The Stellar Heavens

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AN INTRODUCTION TO THE STUDY OF THE STARS AND NEBULÆ

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PREFACE

Stellar or Sidereal Astronomy is that branch of the science which deals with the number, motions, distances, etc., of the stars. The term may be extended to include the nebulæ.

The following pages contain descriptions and details of the most interesting objects among the stars and nebulæ. The information has been carefully brought up to date, and will, it is hoped, be found useful to the beginner, as well as to the more advanced student of the stellar heavens.

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CHAPTER I

THE STARS

The Constellations—Number of Stars—Star Magnitudes—Colours of Stars—Spectra—Parallax and Distance—Absolute Size—Proper Motions—The Sun's Motion in Space.

The Constellations.—The stars visible to the naked eye have been divided into groups, called constellations. These are now chiefly used for the purpose of reference, but in ancient times they were associated with the figures of men and animals, etc. The origin of these constellation figures is somewhat doubtful, but they are certainly of great antiquity. Ptolemy's constellations were 48 in number, but different writers, from the first century B.C., give various numbers, ranging from 43 to 62. Bayer's Atlas, published in 1603, contains 60, 12 new constellations in the Southern Hemisphere having been added by Theodorus to Ptolemy's original 48. The present number is 84. Bayer's Atlas was the first to show the Southern sky, and the first to designate the brighter stars by the letters of the Greek alphabet, α (alpha),

β (beta), γ (gamma), δ (delta), etc. (see Appendix, Note K). Flamstead published an Atlas in 1729. Maps and catalogues of the naked-eye stars have been published in recent years by Argelander, Behrmann, Heis, Houzeau, Proctor, and others. Of these Heis's is, perhaps, the most reliable—at least, so far as accurate star magnitudes are concerned. They extend from the North Pole to 30° south of the Equator. Behrmann's maps are confined to the Southern Hemisphere between the South Pole and 20° south of the Equator. Houzeau's Atlas shows *both* hemispheres, all the stars having been observed by himself in Jamaica and South America. The maps of the 'Uranometria Argentina,' by Gould, show all the Southern stars to the seventh magnitude (and some north of the Equator), but many of these are beyond the reach of ordinary good eyesight. An opera-glass will, however, show them all.

The figures representing the constellations were originally drawn on spheres, or celestial globes, as they are now called. They are therefore reversed, the stars being supposed to be viewed from the centre of the sphere. The ancient astronomers attributed the invention of the sphere to Atlas. It seems certain that a celestial sphere was constructed by Eudoxus so far back as the fourth century B.C. Strabo speaks of one made by Krates about the year 130 B.C., and, according to Ovid, Archimedes had constructed one at a considerably earlier period. None of these ancient spheres have been preserved. There is, however, in the Vatican a fragment in marble of a Greco-Egyptian planisphere, and a globe in the museum of Arolsen, but these are of much later date.

Our knowledge of the original constellation figures is derived from the accounts given by Ptolemy and his successors, and from a few globes which only date back to the Arabian period of astronomy. Among the Arabian globes still existing, the most famous is that preserved in the Borgia Museum at Velletri in Italy. It is made of copper, and is supposed to have been made by a person called Caisar, who was executed by the Sultan of Egypt in the year A.D. 1225. The most ancient of all is one discovered some years ago at Florence. It is supposed to date back to A.D. 1081, and to have been made by Meucci. There is also one in the Farnese Museum at Naples, made in A.D. 1225. Of modern celestial globes, the oldest is one made by Jansson Blaeu in 1603. This shows all the constellations of both hemispheres. Ptolemy's figures of the constellations were restored by the famous painter Albert Dürer, of Nuremberg, in 1515, and the figures on modern globes and maps have been copied from this restoration. Dürer's maps are now very rare. A list of the constellations, with the Arabic names of the principal stars, will be found in the Appendix (Note A).

Number of the Stars.—The number of stars visible to the naked eye is much less than might be supposed from a casual glance at the sky. To ordinary good eyesight about 7,000 stars are visible in the *whole* heavens, and therefore only 3,500 at any given time and place. The total number visible in the largest telescopes is probably about 100,000,000.

In the famous catalogue of Hipparchus, formed in the year 127 B.C., there are only 1,025 stars. Al-Sufi's 'Description of the Heavens,' written in the tenth century, includes 1,018 stars, but he refers to many others, without, however, giving their exact position. The famous German astronomer Heis—who had keen eyesight—shows in his Atlas 3,903 stars visible to the naked eye north of the Equator and 1,040 more between the Equator and 20° south declination, or a total of 4,943 stars between the North Pole and 20° south declination. If we suppose the remainder of the sky to be of the same richness, this would give a total of 7,366 stars visible to the naked eye in both hemispheres. Behrmann, in his Atlas of the Southern heavens, shows 2,344 stars between 20° south declination and the South Pole. This gives 7,124 stars for the whole sky. Adding all those seen by Heis and Behrmann, we have for the whole sky 7,287 stars. The average of these three results is 7,259. The Belgian astronomer Houzeau, who observed the stars in both hemispheres, shows a total of 5,719 for the whole sky. These observers noted all stars down to 6·7 magnitude, or slightly below the sixth magnitude, which is supposed to be about the limit of ordinary eyesight. Persons with exceptionally keen vision may perhaps see a slightly larger number. For stars to the seventh magnitude, Gould found a total of 7,685 stars between the South Pole and 10° north of the Equator. This gives for the whole sky a total of 13,096 stars to the seventh magnitude. Mr. Gavin J. Burns finds from the Harvard photometric measures a total of 4,339 stars down to magnitude 5·99 in the whole sky, and the present writer finds from the 'Harvard Photometric Durchmusterung' a total of 7,848 stars from 6·0 to 6·99 between the North Pole and 40° south declination, which would give for the whole sky 9,554 stars from 6·0 to 6·99 magnitude.[1] Adding this to Mr. Burns' result, we have a total of 13,893 stars down to magnitude 6·99. There are, probably, not very many people, however, who could see a star of the seventh magnitude without optical aid.

As we descend in order of faintness, the number of stars rapidly increases, but until the photographic charts of the heavens, now in progress, have been completed, it is not easy to estimate the probable number visible in the largest telescopes. Sir William Herschel, in his 'gauges' of stars in the Milky Way, made with a reflecting telescope of 18·7 inches aperture, found about 500 stars to the square degree. As the whole star sphere contains 41,253 square degrees (see Appendix, Note B), this would give a total of about 200,000,000 for the whole sky. But the Milky Way is of course exceptionally rich in small stars, and does not represent the whole heavens. Taking the area covered by the Milky Way as one-fourth of the star-sphere—a very liberal estimate—and its richness as five times that of the remainder of the sky (on an average), I find a total of about 82,000,000. A photograph of a rich Milky Way spot in the constellation Cygnus, taken by Dr. Roberts in 1898, shows 30,000 stars in a space of three and a half square degrees. This would give a total of about 360,000,000. But another photograph, taken near the pole of the Milky Way with the same

[1] *Journal British Astronomical Association*, January, 1902.

telescope, would indicate a total of only 7,500,000. We may therefore conclude that a total of about 100,000,000 will not be very far from the truth. This is the number now usually assumed by astronomers.

Star Magnitudes.—The most casual observation will show that the stars differ considerably in their apparent brightness. St. Paul says 'one star differeth from another star in glory.'[1] Indeed, there are stars of all degrees of brightness—from Sirius, the brightest star in the heavens, down to the faintest visible in the largest telescopes on the clearest nights. The term 'magnitude,' when applied to the stars, means their apparent brightness, not their absolute size, which in most cases is unknown. Ptolemy divided those visible to the naked eye into six classes, the brightest being called first magnitude; those considerably fainter, the second; those much fainter still, the third; and so on to the sixth magnitude, which were supposed to be the faintest, just visible to the naked eye on a clear and moonless night. Thus, the larger the number, the fainter the star. Ptolemy only noted whole magnitudes, but the Persian astronomer Al-Sufi, in the tenth century, divided these magnitudes, for the first time, into thirds. Thus, a star slightly fainter than an average star of the first magnitude he called 1-2—that is, nearer to 1 than 2; one a little brighter than the second he called 2-1, or nearer 2 than 1; and so on. This method[2] has been followed in modern times by Argelander, Behrmann, Heis, and Houzeau, but in the photometric catalogues of Harvard, Oxford, and Potsdam the magnitudes are measured to two decimals of a magnitude. This has been found

[1] 1 Cor. xv. 41.

[2] A short *line* between the figures; *not* a comma or point, as sometimes stated.

necessary for greater accuracy, as the heavens contain stars of all degrees of brightness.

Although the ancient astronomers included all the very brightest stars in the first magnitude, there are in reality several stars brighter than a standard star of the first magnitude, such as Aldebaran (α Tauri). These are Sirius, which is nearly eleven times brighter than Aldebaran (according to the revised measures at Harvard); Canopus (α Argûs), the second brightest star in the heavens and about two magnitudes brighter than Aldebaran; Arcturus, Vega, α Centauri, Capella, Rigel, Procyon, α Eridani, Altair, β Centauri, and α Orionis (Betelgeuse). Of these, Canopus, α Centauri, α Eridani, and β Centauri are Southern stars, and do not rise above the English horizon. Al-Sufi noted thirteen stars of the first magnitude[1] visible at his station in Persia, and Halley enumerated sixteen in the whole sky. According to the Harvard photometric measures, there are thirteen stars in both hemispheres brighter than Aldebaran, which is rated 1·07 (see Appendix, Note C).

For the study of the stars and constellations Proctor's large Atlas is perhaps as good as any other. The meaning of the term 'magnitude' is the ratio between the light of any star and that of another exactly one magnitude fainter. This ratio has been variously estimated by different astronomers, and ranges from 2·155, found by Johnson in 1851, to 3·06, assumed by Peirce in 1878. The value now universally adopted by astronomers is 2·512 (of which the logarithm is 0·4). This number is nearly a mean of all the estimates made, and agrees with the value found by Pogson in 1854 by means of an oil flame, and by Rosen with a Zöllner photometer in 1870. It simply means that a star of the first magnitude is 2·512 times the brightness of a star of the second magnitude; a star of the second 2·512 times brighter than one of the third, and so on. This makes a star of the first magnitude just a hundred times brighter than one of the sixth. Thus, Aldebaran is equal in

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[1] Including the star θ Eridani, which is now only of the third magnitude, and has probably faded in brilliancy since Al-Sufi's time.

brightness to 100 stars of the sixth magnitude, and Sirius would be equal to a close cluster of about 1,100 sixth-magnitude stars (see Appendix, Note I).

The following may be taken as examples of stars of the different magnitudes; they are derived from the Harvard measures: First magnitude, Aldebaran and Spica; second magnitude, β Aurigæ and β Canis Majoris; third magnitude, ι Aurigæ and β Ophiuchi; fourth magnitude, θ Herculis and ε Draconis; fifth magnitude, ρ Ursæ Majoris and ω Sagittarii. Stars of about the sixth magnitude are, of course, numerous, and lie near the limit of ordinary naked-eye vision, although on clear moonless nights still fainter stars may be 'glimpsed' by keen-eyed observers.

The 'sun's stellar magnitude' is the number which represents the sun's brightness as seen from the earth on the above scale of star magnitudes. Various estimates of its value have been made, ranging from -26 to -27, and it may be taken at about $-26{\cdot}5$ (or about 8,954,000,000 times brighter than Sirius).

Colours of Stars.—As may be noticed with a little attention, the stars visible to the naked eye are of different shades of colour. Some are white, or even slightly bluish, like Sirius or Vega. Some are distinctly yellowish, as Capella. Some have an orange hue, like Arcturus, and some are notably reddish, like Aldebaran, Antares, and Betelgeuse. Perhaps the reddest star visible to the naked eye is μ Cephei, 'the garnet star' of Sir William Herschel; but as it is only about the fourth magnitude, its colour is hardly perceptible without an opera-glass. Other reddish stars are α Hydræ, called 'the Red Bird' by the ancient Chinese, η and μ Geminorum, μ and ν Ursæ Majoris, δ and λ Draconis, β Ophiuchi, γ Aquilæ, etc. In the Southern Hemisphere ϵ Crucis (in the Southern Cross) is decidedly red, and μ Muscæ, δ^2 and π^1 Gruis, and others, are very reddish. There is some reason to think that Sirius—which is now a white star—was red in ancient times, but the evidence is not conclusive. The variable star Algol is, however, distinctly described as red by Al-Sufi in the tenth century. It is now white, and there can be little or no doubt that it has changed in colour since Al-Sufi's time. This change of colour in Algol seems to lend support to the supposed change of colour in Sirius. Among the telescopic red stars there are several which have been suspected of being variable in colour. There is no star visible to the naked eye of a well-marked bluish or greenish colour, although among the telescopic double stars almost all colours seem to occur.

A catalogue of red stars was published some years ago by Mr. John Birmingham, of Tuam, Ireland. This was revised and extended by the Rev. T. E. Espin, F.R.A.S., in the year 1888. Both these catalogues were published by the Royal Irish Academy. Red stars are remarkable from the fact that their spectra differ considerably from that of our sun, thus showing a different physical constitution. Among them are many of the most remarkable of the variable stars, an interesting class of objects which will be considered in another chapter. A list of the most remarkable red stars at present known will be found in the Appendix, Note D.

Spectra of the Stars.—The spectrum of a star is the narrow rainbow-tinted band of light which is formed by the star's light when it is passed through a narrow slit and a prism. Spectra may also be obtained by placing a prism in front of the object-glass of a telescope. These spectra are crossed by dark lines, and sometimes by bright ones. The spectra of stars differ considerably; some being very similar to the spectrum shown by our own sun, and others of quite a different character, thus indicating a different physical constitution.

The spectra of the stars have been divided into different classes or types, according to their character. The following is Vogel's classification :

Class I.—Spectra in which the metallic lines, or lines shown by the metals, are extremely faint or entirely invisible. The stars are usually white. Examples: Sirius, Vega, Regulus, Spica, Fomalhaut, etc.

Class II.—Spectra in which the metallic lines are numerous and very visible. Colour of the stars, white or yellow. Examples: Capella, Arcturus, Pollux, the Sun, etc.

Class III.—Spectra in which, besides the metallic lines, there are numerous dark bands in all parts of the spectrum, and the blue and violet portions are faint. Colour of the stars, orange or red. This class has been subdivided into:

(*a*) Dark bands, fainter towards the red end. Examples: α Herculis, Betelgeuse, α Ceti, β Pegasi, etc. Many of the variable stars belong to this type. Some show a few bright lines.

(*b*) Bands very wide, and fainter towards the violet; some show a few bright lines. Examples: 19 Piscium, U Hydræ. This is a comparatively rare type. Class III. (*b*) was called Class IV. by Secchi.

Class V. includes stars with bright lines in their spectra. They are also known as the 'Wolf-Rayet stars,' and are comparatively few in number.

The above classes have been subdivided into a number of others.

The first type is usually called 'the Sirian type,' and the second 'the Solar type.'

In Class III. (*b*), = Class IV., the dark bands agree in position with the *bright* bands shown by burning alcohol. They have been called 'carbon stars,' and show no evidence of the presence of hydrogen.

The spectra of the gaseous nebulæ show bright lines on a dark background. Some forty lines or more have been observed. Two of them are identical with lines of hydrogen; and there is also evidence of the presence of carbon, iron, calcium, and probably magnesium. But the 'chief nebular line,' and another, have not yet been identified with those of any known terrestrial substance. This hypothetical substance has been termed 'nebulum.'

The presence of oxygen has been determined in the spectra of the stars β Crucis and β and ε Canis Majoris; also hydrogen, helium, and probably carbon and magnesium. Sir William Huggins finds that in stars whose spectra show strong lines of helium, such as Rigel and Bellatrix, there are dark lines which probably coincide with the lines of nitrogen. These and some others belong to a subdivision of Class I., known as 'the Orion type.' Professor Pickering divides each class into subclasses designated by capital letters. Class I. is divided into subclasses A, B, C, D, Class II. into E to L, Class III. is called M, and Class IV. N.

Parallax and Distance of the Stars.—The distance of a star from the earth is found by measuring its parallax. The 'parallax' of a star is the small angle subtended at the star by the radius of the earth's orbit round the sun, or, in other words, the mean distance between the earth and sun. This is the 'astronomical unit' for all sidereal measurements. This small angle is found by measuring the apparent change of place in the position of a star caused by the earth's change of place in its annual motion round the sun. The measurements, which are very difficult and delicate, are usually made at intervals of six months, when the earth is at opposite points of its orbit. The parallax is always very small, showing that the stars lie at a vast distance from the earth.

There is no star known with a 'parallax' of even one second of arc. The parallax of the nearest fixed star, α Centauri, is only 0·75 of a second. From this the distance of the star in miles is easily computed, and comes out about twenty-five and a half billions of miles—that is, twenty-five and a half millions of millions of miles (see Appendix, Note E). The great majority of the stars are at such a vast distance from the earth that the parallaxes of only a few have hitherto been determined with any approach to accuracy. The following are, perhaps, the most reliable parallaxes yet found :

Star.	*Parallax.*	*Distance in Billions of Miles.*	*Distance in 'Light Years.'*	*Proper Motion.*[1]	*Velocity in Miles across the Line of Sight.*[1]	*Photometric Magnitude.*	*Spectrum (Pickering).*
α Centauri ...	0·75″	25·5	4·34	3·7″	14·5	0·20	II (G)
Ll. 21,185 ...	0·46	41·6	7·08	4·7	30	7·3	—
61 Cygni ...	0·39	49	8·35	5·2	39	5·06	II (H)
Sirius ...	0·37	51·7	8·80	1·3	10	− 1·62	I (A)
O. A. 18,609	0·35	54·7	9·31	—	—	—	—
Procyon ...	0·32	60	10·18	1·3	12	0·47	II (F 5 G)
τ Ceti ...	0·31	62	10·5	1·95	18	3·6	II (G ?)
Cordoba Zone V. 243 ...	0·31	62	10·5	8·7	82	8·5	—
μ Cassiopeiæ	0·24	80	13·57	3·7	45	5·22	II (H)
Altair ...	0·23	83·2	14·16	0·65	8	0·74	I (A 5 F)

For the ten brightest stars in the Northern Hemispheres, the following parallaxes have been recently found at the Yale University Observatory (U.S.A.):

	Parallax.	*Magnitude, Harvard.*
Arcturus	0·024″	0·07
Vega	0·082	0·10
Capella	0·081	0·24
Procyon	0·325	0·47
Altair	0·231	0·74
α Orionis	0·023	0·94[2]
Aldebaran	0·107	1·07
Pollux	0·056	1·25
α Cygni	− 0·012	1·25
Regulus	0·022	1·34

[1] See under 'Proper Motions.' [2] Variable.

Sir David Gill thinks that the parallax of Rigel (β Orionis) is not greater than 0·01″. Hence the star's distance is at least twenty million times the sun's distance from the earth, or a journey for light of about 326 years!—and yet it is one of the brightest stars in the heavens!

Absolute Size of the Stars.—As the stars show no perceptible disc—like the planets—even with the largest telescopes,[1] it is impossible to determine their actual size, even when their distance from the earth is known. In some cases, however, it is possible to make a probable estimate. Thus, in the case of α Centauri, we know that our sun, if placed at the same distance as the star, would appear somewhat fainter than the star does to us (see Appendix, Note F); and as the spectrum of the star's light is very similar to the solar spectrum, we may conclude with much probability that it does not differ very widely from the sun in size and physical constitution. The star is a binary, or revolving double star, and from its orbit and parallax it has been computed that the mass of the system is about twice the mass of the sun. This confirms the conclusion derived from its apparent brightness and spectrum.

It is now known that stars of the first or Sirian type are much brighter in proportion to their mass than those of the second or solar type. Thus, Sirius, which is also a binary star, has (with its faint companion) a mass of about three and a half times the sun's mass (the mass of the bright star being 2·36 times the sun's mass). But Sirius is very much brighter than the sun would be if placed at the same distance. The sun would, I find, if placed at the distance of Sirius, shine as a star of below the second magnitude, or nearly four magnitudes fainter than Sirius. Stars of the Sirian type are therefore probably of larger size and less density than our sun. With

[1] A small *apparent* disc is visible in a telescope, but this is merely an optical effect, and is called 'the spurious disc.'

reference to stars of the other types of spectra, we have no means of judging of their absolute size, as the distances of very few, if any, have been determined with any approach to certainty.

Proper Motions.—Many of the stars have what is called a 'proper motion'—that is, a motion, apparent or real, on the background of the sky. The motion may be only apparent, and due to the sun's motion in space, or it may be due to a real motion of the star itself. Probably in most cases both causes combine to produce the observed motions. These motions are, of course, very small, and can only be detected by telescopic observations; but they accumulate in the course of ages, and in some cases the change since ancient times has been so considerable as to become appreciable to the naked eye. The proper motions of the stars were first detected by Halley in 1715, and J. Cassini in 1718 found that while Arcturus had moved with reference to the ecliptic since earlier observations, the position of the star η Boötis was unchanged.

The star with the largest proper motion known was for many years the star 1830 of Groombridge's catalogue, called 'the runaway star' by Professor Newcomb. It has a 'proper motion' of about seven seconds of arc per annum. But a star with a still larger proper motion has recently been discovered by Mr. Innes and Professor Kapteyn. It is a star of the eighth magnitude in the Southern constellation Pictor, and has a proper motion of about 8·7″ per annum. Other stars with large proper motions are the following: Lacaille 9352 (7·5 magnitude), 6·94″; Cordoba 32,416 (8·5 magnitude), 6·07″; 61 Cygni (5·1 magnitude), 5·2″; Lalande 21,185 (7·3 magnitude), 4·76″); ε Indi (5·2 magnitude), 4·61″; Lalande 21,258 (8·6 magnitude), 4·41″; 40(o^2) Eridani (4·4 magnitude), 4·05″; μ Cassiopeiæ (5·2 magnitude), 3·73″. There are several others with proper motions of 3·7″ to 2·0″, and a large number with motions of less than 2·0″.

As mentioned above, the proper motion has in some cases accumulated to such an extent in the course of ages as to become perceptible to the naked eye. An interesting case of this kind is that of the star 61 Virginis. Al-Sufi, the Persian astronomer, in his 'Description of the Heavens,' written in the tenth century, speaks of 61 Virginis as a double star of the fifth magnitude, but it is now a single star, as seen with the naked eye. This is due to the fact that it was in Al-Sufi's time close to the star 63 Virginis, but has since moved away about one degree towards the south-west. This interesting fact was pointed out by Professor Moye in the *Observatory* for December, 1900.

The star μ Cassiopeiæ, which lies near θ Cassiopeiæ, has a proper motion of about 3·7″ of arc per annum, and about 4,000 years ago must have been close to the star α Cassiopeiæ, and might have been so seen by the ancient astronomers.

Among telescopic double stars, one of the companions of the triple star Struve 1516, which was to the west of the primary star in the year 1831, is now—owing to the proper motion of the brighter star—to the east of it (see Appendix, Note G).

In addition to the proper motions across the line of sight, which we have just considered, motion *in* the line of sight, either towards the earth or away from it, has been observed in many stars by means of the spectroscope. This motion produces the effect of a shifting of the dark lines in the star's spectrum from their normal position. If the star is moving towards the earth, the lines are shifted towards the blue end of the spectrum, and if the star is receding from the earth, they are shifted towards the red end. From the measured amount of this shift the velocity in miles per second at right angles to the line of sight can be easily computed.

The following large motions in the line of sight have been observed, among others :

STARS APPROACHING THE EARTH.

Star.		Velocity per Second.	
		Kilometres.	*Miles.*
μ Cassiopeiæ	... ...	97·4	60
1830 Groombridge	... ...	95	59
ε Andromedæ	... ...	83·7	52
μ Sagittarii	... ...	76	47
1 Pegasi	... ...	75	46½
η Cephei	... ...	74	46
Nebula G.C. 4373	... ...	65	40

STARS RECEDING FROM THE EARTH.

θ Canis Majoris	... ...	96	59·5
δ Leporis	... ...	95	59

A motion of approach is indicated by the sign −, and recession by +.

Professor Campbell finds the *average* velocity of the stars about 34 kilometres, or 21 miles a second; so the above high velocities seem to be exceptional.

The Sun's Motion in Space.—An examination of stellar proper motions has led astronomers to the interesting conclusion that the sun and solar system are moving through space with a considerable velocity. This is a result which might have been anticipated from a consideration of stellar proper motions. Thomas Wright of Durham, writing in the year 1750, remarked that 'the sun is a star, and the stars are suns'; and as most of the stars are apparently in motion, the sun is most probably moving, too. The reality of this solar motion has been placed beyond doubt by the fairly accordant results of all computers. Sir William Herschel in 1783 was the first to investigate the matter. He found that the sun was moving towards a point in the constellation Hercules, near the star λ, a result which does not differ much from modern determinations. Calculations in recent years place the point a little to the north-east of Herschel's position, and not far from the bright star Vega (α Lyræ).

The point towards which the sun is moving is termed the 'solar apex,' or 'apex of the solar way.' The following position of the 'apex' will show the general accordance of the results found:

	Right Ascension.	*Declination.*
Sir William Herschel ...	260·6°	+26·3°
Rancken	284·6	+31·9
L. Struve	273·3	+27·3
"	266·7	+31
O. Stumpe	287·9	+31·9
"	285·2	+30·4
Newcomb	277·5	+35
Campbell	277·5	+20
Kapteyn	273·6	+29·5

The actual velocity with which the sun is speeding through space has been variously computed in recent years from about 6 to 14 miles a second. Professor Campbell finds about 12⅓ miles a second, and from a recent investigation of stellar motions Professor Kapteyn considers that a velocity of 18·45 kilometres, or 11·44 miles, a second is 'the most probable value that can at present be adopted.'[1] This is about four times the radius of the earth's orbit per annum—that is, four times the earth's mean distance from the sun.

Eberhard, Keeler, and Vogel have found a motion of recession in the great nebula in Orion of about 17½ kilometres, or 10·85 miles, a second. This probably represents the sun's motion in nearly the opposite direction.

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[1] *Proceedings of the Royal Academy of Amsterdam*, 1901, pp. 674, 675.

CHAPTER II

DOUBLE, MULTIPLE, AND BINARY STARS

Double Stars — Naked-eye Doubles — Telescopic Doubles—Triple Stars—Multiple Stars—Discovery of Binary Stars—Orbits of Binary Stars—Spectroscopic Binaries.

Double Stars.—Double stars are those which appear as single stars to the naked eye, but when examined with a telescope of sufficient power are seen to consist of two components. There are some stars which appear double to the naked eye, and these have been called 'naked-eye doubles,' but these wide objects are not really double stars in the true sense of the term. The name 'double star' (διπλους) was first used by Ptolemy in speaking of ν Sagittarii, which consists of two small stars close together, as seen with the naked eye. The first real double star discovered with the telescope seems to have been ζ Ursæ Majoris (Mizar), the middle star in the 'tail' of the Great Bear, or 'handle' of the Plough, which was seen by Riccioli about the middle of the seventeenth century. The quadruple star θ Orionis was seen by Huygens in 1656, and the double star γ Arietis by Hooke in 1664, while he was observing the comet of that year. In 1678 the stars Castor and β Scorpii were seen double by J. D. Cassini. In 1689 Richaud in India saw α Centauri double, and in 1718 γ Virginis was doubled by Bradley and Pound. La Condamine, during his journey in Peru, saw α and ζ Crucis double. 61 Cygni was seen double in 1753, and β Cygni in 1755.

Naked-eye Double Stars. — Among these may be mentioned the following: Mizar (referred to above as a telescopic double) has near it a small star known to the old Arabian astronomers as Alcor. This can be seen with ordinary good eyesight. α_1 and α_2 Cancri are easily seen. The star α Capricorni consists of two stars which, although closer than Mizar and Alcor, are more equal in brightness, and can be easily seen with the naked eye on a clear night. ζ Ceti has near it a small star (χ Ceti) easily visible. ν Sagittarii has been already mentioned. θ Tauri, in the Hyades, is another pair which some eyes can see without optical aid, and also κ Tauri, a little north of the Hyades. o Cygni is another example. Near γ Leonis is a star of the sixth magnitude which some can see with the naked eye. Perhaps the most difficult object for naked-eye vision is ϵ Lyræ, the northern of two small stars which form a little triangle with the bright star Vega. This to some eyes appears double, but it is a difficult test. An opera-glass will show it distinctly. This is a very remarkable object, as, viewed with a good telescope, each of the components is a close double star, and there are several faint stars between the pairs.

Telescopic Double Stars. — There are thousands of telescopic double stars now known, and the list is being constantly added to. Many of these may be seen in small telescopes of two to four inches in aperture, while many others are so close as to require the highest powers of the largest telescopes to show them as anything but single stars. Among these latter are included many binary or revolving double stars, which will be considered further on. The 'position angles' of double stars are measured from the north point of the 'field of view' round by east, south, and west, back to the north point again. In an astronomical telescope, in which the image is inverted, the north point is, of course, the lowest point in the 'field.'

Among double stars visible with small telescopes of, say, three to four inches in aperture, the following may be mentioned. They are given in order of right ascension, and the positions are for 1900.

α Cassiopeiæ: 0 h. 34·8 m., N. 56° 0′; magnitudes, 2, 9; position angle, 280·2°; distance, 63·2″. Yellow, bluish. A very wide double star, but the companion is faint in small telescopes

6 Eridani: 1 h. 36 m., S. 56° 43′; 6, 6; 223·5°; 7·73″ (1900).[1]

γ Arietis: 1 h. 48 m., N. 18° 49′; 4·2, 4·4; 358·3°; 8·32″ (1896). White, yellow.

α Piscium: 1 h. 56·9 m., N. 2° 17′; 2·8, 3·9; 335·7°; 3·6″. Greenish-white, bluish.

γ Andromedæ: 1 h. 58 m., N. 41° 51′; 3, 5; 65·4°; 10·3″ (1898). Gold and blue. One of the finest double stars in the heavens. The companion is double; but it is a binary or revolving double star, and has now closed up and become a very difficult object in recent years.

θ Eridani: 2 h. 54·5 m., S. 40° 42′; 3·5, 5·5; 84·9°; 8·21″. White, light yellow. A splendid double star; one of the finest in the sky, but not visible in England.

ζ Persei: 3 h. 47·8 m., N. 31° 35′; 2·7, 9·3; 207·6°; 12·5″. Greenish-white, ash-coloured. Three other distant companions.

ϵ Persei: 3 h. 51·1 m., N. 39° 43′; 3·1, 8·3; 7·8°; 8·81″ (1900). Greenish, bluish-white.

β Orionis (Rigel): 5 h. 9·7 m., S. 8° 19′; 1, 8; 203·8°; 9·28″ (1902). White. The colour of the companion has been variously stated.

ζ Orionis: 5 h. 35·8 m., S. 2° 0′; 2, 5·7; 155·7°; 2·41″ (1900). White, olive.

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[1] Date of measure.

α Geminorum (Castor): 7 h. 28·2 m., N. 32° 7′; 2·7, 3·7; 225·7°; 5·6″ (1900). This is in reality a triple star, the spectroscope showing the brighter star to be a close double.

γ Leonis: 10 h. 14·4 m., N. 20° 22′; 2, 3·5; 117·0°; 3·83″ (1902). Yellow.

γ Centauri: 12 h. 36·0 m., S. 48° 25′; 4, 4; 355·7°; 1·54″ (1902, Innes). Binary.

γ Virginis: 12 h. 36·6 m., S. 0° 54′; 3, 3; 329·3°; 5·89″ (1902). Yellowish.

12 Canum Venaticorum (Cor Caroli): 12 h. 51·4 m., N. 38° 52′; 3·2, 5·7; 227·3°; 19·9″. White.

ζ Ursæ Majoris (Mizar): 13 h. 19·9 m., N. 55° 27′; 2·1, 4·2; 147·6°; 14·4″. Greenish, white. The brighter star is a spectroscopic double.

α Centauri: 14 h. 32·8 m., S. 60° 25′; 1, 2; 211·2°; 21·63″ (1902—Innes). Nearest star to the earth, and a binary; period about eighty-one years (See).

ε Boötis: 14 h. 38 m., N. 27° 31′; 3, 6·3; 326·6°; 2·81″ (1900). Yellow, blue. A beautiful object, and a test for telescopes of moderate power.

β Scorpii: 15° 59·6′ m., S. 19° 31′; 2, 5; 24·8°; 13·6″. Orange, pale yellow. Burnham found the brighter star to be a close double.

α Herculis: 17 h. 10·1 m., N. 14° 30′; 3, 6·1; 112·9°; 4·75″ (1899). Orange, green.

70 Ophiuchi: 18 h. 0·4 m., N. 2° 32′; 4·5, 6·0; 246·9°; 1·61″ (1900). Yellow, purple. A well-known binary star.

Vega (*α* Lyræ): 18 h. 34 m., N. 38° 41′; 1, 10·5; 159·8°; 51·3″ (1892).

θ Serpentis: 18 h. 51·2 m., N. 4° 4′; 4·5, 4·7; 103·8°; 21·6″. Yellowish, white. A fine wide pair.

γ Coronæ Australis: 18 h. 59·7 m., S. 37° 12′; 6, 6; 139°; 1·58″ (1901). A binary; period about 154 years; angle decreasing.

β Cygni: 19 h. 26·7 m., N. 27° 45′; 3, 5·3; 55·2°; 34·19″. Yellow, blue. A fine object for a small telescope.

ε Draconis: 19 h. 48·5 m., N. 70° 1′; 4, 7·5; 354·5°; 2·8″. Yellow, blue.

γ Delphini: 20 h. 42 m., N. 15° 46′; 4, 5; 270·6°; 11·2″ (1889). Gold and bluish-green.

61 Cygni: 21 h. 2·1 m., N. 38° 13′; 5·3, 5·9; 124·9°; 22″ (1900). The nearest star in the Northern Hemisphere.

δ Equulei: 21 h. 9·6 m., N. 9° 36′; 4·1, 10·2; 38·8°; 27·4° The bright star is a close binary—one of the most rapid known.

μ Cygni: 21 h. 39·6 m. N. 28° 17′; 4, 5; 123·4°; 2·59″ (1900). White, bluish-white.

ζ Aquarii: 22 h. 23·7 m., S. 0° 32′; 4, 4·1; 324·0°; 3·1″ (1891). Pale yellow. Perhaps a binary star with a long period.

δ Cephei: 22 h. 25·4 m., N. 57° 54′; 3·7-4·9, 5·3; 192·0°; 40·9″. Yellow, blue. The brighter component is a well-known variable star.

The number of known double stars now amounts to several thousands, and are being constantly added to. Most of the recent discoveries are, however, very close, and only to be seen with large telescopes.

Triple Stars.—These are very interesting objects, and consist of three stars close together, instead of two. In some cases there is a physical connection between the stars. In others the connection seems to be only an optical one, the fainter stars probably lying far behind the brighter stars in space.

The following are some interesting examples of triple stars:

o^2 (40) Eridani: 4 h. 10·7 m., S. 7° 47′; 4, 9; 107·5°; 85·3″; 9 again double: 9·1, 10·8; 98·6°; 2·6″ (1891). A binary. Large common proper motion of about 4·1″ per annum.

15 Monocerotis: 6 h. 35·5 m., N. 10° 0′; 6, 8·8, 11·2; 213·6°, 13·5°; 2·8″, 16·6″. Green, blue, orange.

12 Lyncis: 6 h. 37·4 m., N. 59° 32′; 5·2, 6·1, 7·4; 114·8° (1900), 304·2°; 1·48″, 8·7″. Greenish, white, bluish. The close pair is a binary; long period.

α Crucis: 12 h. 21·0 m., S. 62° 32′; 2, 2, 6; 117·6°, 201·8°; 4·95″, 89·8″. This is the brightest star in the Southern Cross.

β Equulei: 21 h. 18 m., N. 6° 23′; 5, 14, 15; 308·7°, 275·9°; 67·4″, 86·3″. A good test for a four-inch refractor; 14 is again double.

Multiple Stars.—These consist of four or more components.

The following are good examples :

θ Orionis : 5 h. 29 m., S. 5° 28′ ; 6, 7, 7·5, 8 ; AB, 32·3° ; 8·7″ ; AC, 131·3° ; 12·9″ ; DC, 240·6° ; 13·3″. This is the well-known 'trapezium' in the great nebula in Orion. Near A is a faint star (Struve), and near C is another (Herschel), and there are other fainter stars in the group. The four bright stars can be easily seen with small telescopes. I have seen them with one-and-a-half inch (reduced aperture) in the Punjab sky.

σ Orionis : 5 h. 33·7 m., S. 2° 39′ ; 4·0, 9·5, 6·8, 6·3 ; 236·5°, 84·5° ; 11″, 12·9″. 6·8 and 6·3 : 230·8°, 30″. Burnham found the bright star to be a close double and rapid binary. A second group and other faint stars are in the field. With a four-inch refractor in the Punjab, I saw ten stars in all, four in each group, and two faint stars between the groups.

h 3780 : 5 h. 34 m., S. 17° 59′ ; 7, 8½, 9, 8, 12, 11 ; 6·7°, 136·2°, 298·7°, 45·8°, 104·5° ; 78″, 90″, 125″, 50″, 90″. A beautiful object for small telescopes. Burnham finds that two of these are close double stars in a large telescope. I have seen the six stars given above with a three-inch refractor in the Punjab. They lie about 6 m. to the east of the fourth-magnitude star α Leporis, which is itself a wide double star, 4, 9·5 ; 156·1° ; 35·4″.

ϵ Lyræ : 18 h. 41 m., N. 39° 30′ ; 4½, 4½ ; 172·9° ; 207·1″. Visible in an opera-glass as a double star, and to some with the naked eye. Each star is again double with a two-and-a-half or three-inch telescope ; ϵ^1, 4·6, 6·3 ; 12·5° ; 3·4″ (1900) ; ϵ^2, 4·9, 5·2 ; 130·5° ; 2·5″ (1900). Between the pairs are three fainter stars, and other faint stars are near.

8 Lacertæ : 22 h. 31 m., N. 39° 6′ ; 6, 6·5, 10·2, 8·5 ; AB, 185·7° ; 22·5″ ; BC, 155·7° ; 28·2″ ; BD, 131·6° ; 66·5″. Espin sees a faint companion to D.

Discovery of Binary Stars.—The credit of the discovery of binary or revolving double stars seems to be due to the Rev. John Michell, who about the middle of the eighteenth century deduced from abstract reasoning the probable existence of these revolving suns. The truth of this hypothesis was proved from direct observation by Sir William Herschel, by whom they were accidentally discovered towards the end of the eighteenth century while carrying out researches with a view to finding the distance of some double stars from the earth. 'Instead of finding, as he expected, that annual fluctuation to and fro of one component of a double star with respect to the other—that alternate increase and decrease of their distance and angle of position which the earth's annual motion would produce—he observed in many cases a regular progressive change; in some cases bearing chiefly on their distance, in others on their position, and advancing steadily in one direction, so as clearly to indicate a real motion of the stars themselves.' Careful measurements during a period of twenty-five years confirmed the correctness of this discovery, and established the fact that in many of the double stars the components revolve round each other in periods varying in length, and in orbits differing—in most cases—widely from the circular form; indeed, in some instances in such elongated ellipses as to bear more resemblance to the orbits of comets than to those of planets.

Orbits of Binary Stars.—The first attempt at computing the orbit of a binary star was made by Savary in 1830, in the case of ξ Ursæ Majoris. In the same year the orbit of 70 Ophiuchi was computed by Encke. An orbit for γ Virginis was computed by Sir John Herschel in 1833, and one for Castor in the same year. Since that time a considerable number of orbits have been computed for binary stars by various computers, including Aitken, Burnham, Casey, Celoria, Doberck, Dunér, Flammarion, Glasenapp, Hind, Hussey, Jacob, Klinkenfues, Lewis, Mann, Powell, See, Villarceau, and the present writer. The calculation of a binary star orbit is a matter of considerable difficulty and trouble, and cannot be described here. The most important elements are the period and the semi-axis major of the orbit, as from these the mass of the system can be found, if the star's parallax is known.

An account of the principal results arrived at by astronomers may prove of interest to the reader. The binary stars described are given in order of right ascension. Recent measures of position are given when these are available.

η Cassiopeiæ : R.A., 0 h. 42·9 m., N. 57° 18′ ; magnitudes 4 and 7. Discovered by Sir William Herschel in 1779. Since that year numerous measures have been made, and several orbits have been computed, with periods ranging from 176 years by Dunér to 222 years by Doberck. Dr. See finds 195·76 years, with an eccentricity of 0·5142 and an apparent mean distance (a) of 8·2″ between the components. A parallax of 0·154″ was found by Otto Struve. This combined with See's elements gives the mass of the system about four times the sun's mass (see Appendix, Note H). Comstock, however, finds a period of about 500 years, and a=11·4″. This gives a mass about 1·62 times the sun's mass. Position : 219·9° ; 5·2″ (1899, at Greenwich Observatory). Spectrum, second type (F 8 G).

γ^2 Andromedæ : R.A., 1 h. 57·8 m., N. 41° 51′ ; 5·5, 7. This is the companion of the well-known double star γ Andromedæ. A complete revolution has been described since its discovery by O. Struve in 1842. Burnham found a period of 54·8 years, See 54·0 years, and Hussey 55 years—results in close agreement. The eccentricity of the orbit is very high, about 0·857 according to See. Position : 114·8° ; 0·40″ (1900, Greenwich).

55 Tauri : R.A., 4 h. 14·3 m., N. 16° 16·9′ ; 7·0 and 8·8. Hussey finds a period of 200 years.[1] Position : 61·5° ; 0·39″ (1899, Greenwich).

O. Struve 82 : R.A., 4 h. 17 m., N. 14° 49·3′ ; 7·0 and 9·0. Glasenapp found a period of 158·4 years, Hussey 97·94 years, and the present writer 90·54 years. Position : 123·8° ; 0·51″ (1899, Greenwich).

Sirius (α Canis Majoris) : R.A., 6 h. 40·4 m., S. 16° 34′ ; brighter than 1, and 10. Some irregularities in the proper motion of

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[1] 'Publications of the Lick Observatory,' vol. v., 1901, p. 58.

this brilliant star led Bessel, in 1844, to suggest the probable existence of a disturbing body near Sirius, and Peters, in 1857, calculated a hypothetical orbit for the supposed companion. He found a period of about fifty years, with an ellipse of large eccentricity (nearly 0·8). An investigation was also made by Safford in 1861, which indicated the probable position of the companion, and in 1862 it was discovered by Alvan Clark close to the position assigned by Safford.[1] In 1864 Auwers computed an orbit and found a period of 49·4 years, with an eccentricity of over 0·6. Several other orbits have since been computed, with periods ranging from 48·84 to 58·47 years. See finds 52·2 years, with an eccentricity of 0·620, the orbit being very similar to one found by Burnham. From his own orbit and Gill's parallax of 0·38″, See finds the mass of the system to be 3·473 times that of the sun, the mass of the bright star being 2·360, and that of the faint companion 1·113, times the sun's mass. The large mass of the faint star is very remarkable. Assuming its magnitude at 10 and the magnitude of Sirius at − 1·62, as measured at Harvard, we have a difference of 11·62 magnitudes between the bright and faint star. This denotes that Sirius is 44,470 times brighter than its companion, and, judging from its large mass, the faint star must be a comparatively dark body. Spectrum, first type (A, Pickering).

Procyon (*α* Canis Minoris): 7 h. 34·1 m., N. 5° 29′; 0·47, 13. As in the case of Sirius, irregularities in the proper motion of Procyon were noticed by Bessel in 1844 and by Mädler in 1851. In 1874 Auwers computed an orbit and found a period of about 40 years (39·972). In the years 1888 and 1890 Burnham failed to see any close companion with the thirty-six-inch refractor of the Lick Observatory, but in 1896 it was discovered by Schaeberle with the same instrument, when it was farther from the bright star. Dr. See has computed an orbit, and finds a period of 40·0 years. He finds the mass of the system to be 6 times the sun's mass, the masses of the components being in the ratio of 5 to 1. With Elkin's parallax of 0·266″, the semi-axis major of the orbit (or the mean distance between the components) is 21·2 times the earth's distance from the sun, or a little greater

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[1] This reminds one of the discovery of Neptune.

than the distance of Uranus from the sun. As in the case of Sirius, the faint companion has about the same mass as the sun, and must therefore be a comparatively dark body. The spectrum of Procyon is of the second type (F 5 G, Pickering). Position : 326·0° ; 4·83″ (Schaeberle, 1898). Angle and distance increasing.

9 Argûs : 7 h. 47·1 m., S. 13° 38′ ; 5·7, 6·3. Both yellow. Discovered by Burnham in 1873. A close and difficult double star. Glasenapp found a period of 40½ years, Burnham 23·3 years, and See 22·0 years, with an eccentricity of 0·70. The shorter periods seem to be nearer the truth. The spectrum is of the second type (E, Pickering). Position : 295·9° ; 0·32″ (1899, Greenwich Observatory).

ζ Cancri (AB) : 8 h. 6·2 m., N. 17° 58′ ; 5·5, 6·2. Both yellow. Discovered by Sir William Herschel in 1781. Numerous orbits have been computed, the periods ranging from 42½ to 62½ years. See finds 60 years, and this is probably not far from the truth. Professor Seeliger has investigated the motion of this system (which is triple, or perhaps quaternary), and finds that to make the observations agree with theory it is necessary to assume that the third star is in reality a very close double, the components of which revolve round their centre of gravity, and both round the centre of gravity of the components of the close pair. This hypothesis is, however, disputed by Burnham. The spectrum is of the second type (F 8 G, Pickering). Position : 5·8° ; 1·07″ (1900, Greenwich).

ω Leonis : 9 h. 23·1 m., N. 9° 30′ ; 6, 7. Both yellow. Discovered by Sir W. Herschel in 1782. Various orbits have been computed, with periods ranging from 82½ to 227¾ years. See finds 116·2 years, with an eccentricity of 0·537. The spectrum is of the second type (E, Pickering). Position : 114·3° ; 0·62″ (1900, Greenwich).

φ Ursæ Majoris : 9 h. 45·3 m., N. 54° 33′ ; 5·5, 5·5. Both yellowish. Discovered by O. Struve in 1842. A period of 115 years was found by Casey, and 91·92 years by Glasenapp. See finds 97 years. Spectrum first type (A, Pickering). Position : 284·7° ; 0·27″ (1900, Greenwich).

ξ Ursæ Majoris : 11 h. 12·9 m., N. 32° 6′ ; 4, 5. Yellowish. Discovered by Sir W. Herschel in 1780. A well-known binary star, for which a number of orbits have been computed, with periods from 58¼ to 61½ years. See finds 60 years, with an eccentricity of 0·397. The spectrum is of the second type (G, Pickering). Position: 151·7°; 2·17″ (1900, Greenwich).

O. Struve 234: 11 h. 25·4 m., N. 41° 50′; 7, 7·8. Yellowish. An orbit computed by the present writer in 1886 gave a period of 63·45 years. See finds 77 years. Spectrum second type (E ?). Position: 134·2°; 0·34″ (1899, Greenwich).

O. Struve 235: 11 h. 26·7 m., N. 61° 38′; 6, 7·8. Yellowish. Doberck found a period of 94·4 years, See finds 80 years, and Hussey 66 years. Spectrum second type (F, Pickering). Position: 120·9°; 0·58″ (1900, Greenwich).

Struve 1639 Comæ Berenices: 12 h. 19·4 m., N. 26° 8′; 6·7, 7·9. Lewis finds a period of 180 years, with an eccentricity of 0·70.[1] The spectrum is of the first type (A). Position: 180·1°; 0·15″ (1900, Greenwich).

γ Centauri: 12 h. 36 m., S. 48° 25′; 4, 4. Yellowish. An orbit computed by the present writer gave a period of 61·88 years; See finds 88 years, with an eccentricity of 0·800. Position: 355·7°; 1·54″ (1902, Innes).

γ Virginis: 12 h. 36·6 m., S. 0° 54′; 3, 3·2. Yellow. This famous binary star was discovered by Bradley and Pound in the year 1718, and it has been frequently measured since by observers of double stars. Numerous orbits have been computed, with periods ranging from 141¼ to 628 years. Calculations in recent years vary from 175 to 194 years, found by See. The eccentricity is very high, between 0·8 and 0·9, according to all computers, and is the largest known among binary stars. In fact, the orbit is more like that of a comet than a planet. An entire revolution has been nearly completed since its discovery, so the orbit is now well determined. The component stars are at present nearly at their greatest distance apart, and the pair forms a fine object for small telescopes. From spectroscopic measures of motion in the line of sight, Belopolsky finds a parallax of 0·051″, and a combined mass equal to 15 times the mass of the sun. The spectrum is of the first type (A, Pickering). Position: 329·3°; 5·89″ (1902).

42 Comæ Berenices: 13 h. 5·1 m., N. 18° 4′; 6, 6. Orange.

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[1] *Monthly Notices*, R.A.S., January, 1902.

A fast-moving binary, the period being about 25½ years. The plane of the orbit is in the line of sight, so that the apparent motion is wholly in the distance, the position angle remaining nearly constant. Spectrum of the second type (F). Position : 205·0° ; 0·33″ (1900, Greenwich).

O. Struve 269 : 13 h. 28·3 m., N. 35° 46′ ; 7·3, 7·7. Yellowish. This close and difficult binary star has performed a complete revolution since its discovery by Otto Struve in 1844. An orbit computed by the present writer in 1891 gave a period of 47·7 years ; Burnham finds 48·4, and See 48·8, years—results in fairly close agreement. Spectrum of the first type (A). Position : 218·5″ ; 0·30″ (1900, Greenwich).

25 Canum Venaticorum : 13 h. 33 m., N. 36° 48′ ; 5, 8·5. White, blue. Doberck found a period of about 120 years, and See 184 years. The eccentricity of the orbit is very high, about 0·75. Spectrum of the first type (A). Position : 129·7° ; 0·88″ (1900, Greenwich).

α Centauri : 14 h. 32·6 m., S. 60° 25′ ; 0·50, 1·75. Both orange yellow. This famous binary star—the nearest of all the stars to the earth—was discovered by Richaud in India in December, 1689. Numerous observations of it were made in the eighteenth and nineteenth centuries, and the orbit has now been well determined. A number of orbits have been computed, with periods ranging from 75 to 88⅓ years. From a recent investigation, See finds a period of 81·1 years, which cannot be far from the truth. The apparent orbit is very elongated. Assuming Gill's parallax of 0·75″, See finds that the mass of the system is twice the sun's mass (see Appendix, Note H). The mean distance between the components is a little greater than the distance of Uranus from the sun, but owing to the eccentricity of the orbit (0·528) this distance varies to a considerable extent. Although the components differ a good deal in brightness, their masses are nearly equal. Spectrum of the second type (G). Position : 211·2° ; 21·63″ (1902, Innes).

O. Struve 285 : 14 h. 41·7 m., N. 42° 48′ ; 7·5, 7·6. Yellowish, whitish. A close and difficult double star. A period of 118·5 years was found by the present writer in 1893, but Burnham finds 62 years, and See 76½ years. Position : 124·5° ; 0·26″ (1900, Greenwich).

ξ Boötis: 14 h. 46·8 m., N. 19° 31′; 4·5, 6·5. Yellow, purple. Discovered by Sir William Herschel in 1780. Several orbits have been computed for this fine pair, the periods ranging from 117 to 172 years (Comstock). See finds 128 years. The eccentricity is high, 0·721 according to See's orbit. Spectrum second type (G). Position: 198·2°; 2·98″ (1900).

η Coronæ Borealis: 15 h. 19·1 m., N. 30° 39′; 5·5, 6. Both yellowish. Several orbits have been computed, with periods of 40 to 67 years. Comstock and See both find 41·6 years, which must be very near the truth. Nearly three revolutions have now been described since its discovery by Sir W. Herschel in 1781. Spectrum of the second type (F). Position: 1·3°; 0·63″ (1900, Greenwich).

μ^2 Boötis: 15 h. 20·7 s., N. 37° 43′; 6·5, 8. Both white. Several orbits have been computed, with periods of 146½ to 314 years. See finds 219·42 years. Spectrum first type (B). Position: 69·3°; 0·86″ (1900, Greenwich).

O. Struve 298: 15 h. 32·4 m., N. 40° 10′; 7, 7·4. Both yellowish. A small double star, near φ Boötis. Periods of 51 to 68·8 years have been computed. See finds 52 years. A complete revolution has now been described since its discovery by Otto Struve in 1845. Position: 180·6°; 1·03″ (1900, Greenwich).

γ Coronæ Borealis: 15 h. 38·5 m., N. 26° 36′; 4, 7. Yellow, blue. Orbits have been computed with periods of 73 to 95½ years. The inclination is very high, and the apparent orbit very elongated. Spectrum of the first type (A). Position: 116·1°; 0·48″ (1900, Greenwich).

ξ Scorpii: 15 h. 59 m., S. 11° 5′; 5, 5·2. Both yellow. A remarkable triple star. Several orbits have been computed for the close pair, with periods of 49 to 105½ years. The longer period seems more correct. The eccentricity is small, but the inclination of the orbit plane is high, and the apparent orbit rather elongated. A full revolution has been completed since its discovery by Sir W. Herschel in 1781. All three stars have a common proper motion, and probably form one system, but the motion of the third star is very slow. Position: 213·4°; 0·81″ (1895).

σ Coronæ Borealis: 16 h. 11 m., N. 34° 7′; 6, 7. Yellow, bluish. Various periods have been found, ranging from 195 to 846 years. See finds 370 years. Spectrum of the second type (E). Position : 212·6° ; 4·34″ (1899, Greenwich).

ζ Herculis : 16 h. 37·6 m., N. 31° 47′ ; 3, 6½. Yellow, bluish or reddish. This is a fast-moving binary, and a number of orbits have been computed, with periods of 30 to 36½ years. See finds 35·0 years. A period of 35·55 years was found by Doolittle in 1899, and from a careful discussion of all the observations to 1900 Lewis finds periods of 31·1 to 35·1 years. He computes the probable parallax of the star at 0·14″, and the combined mass of the system 0·89 that of the sun. He thinks there is evidence to show that the companion varies in brightness from 6·5 to 7·5, and its colour from red to blue.[1] He also thinks that the primary star may possibly be a close double. Three complete revolutions have been performed since its discovery by Sir W. Herschel in 1782. The spectrum is of the second type (G, Pickering). Position : 224·1° ; 0·95″ (1900, Greenwich).

β 416 : 17 h. 12·1 m., S. 34° 52′ ; 6·4, 7·8. Both yellowish. A fast-moving binary, discovered by Burnham, who finds a period of 24·7 years. Glasenapp finds 32·23 and 34·85 years, See 33·0 years, and the present writer 34·48 years. The longer periods seem to be near the truth. Position : 320·0° ; 1·30″ (1895, See).

Struve 2173 : 17 h. 25·3 m., S. 0° 59′ ; 6, 6. Both yellow. This is another fast-moving binary, the period being about 46 years. The eccentricity of the orbit is comparatively small, but the inclination of the orbit being high, the apparent orbit is very elongated. Spectrum second type (F ?). Position : 329·5° ; 1·01″ (1900, Greenwich).

τ Ophiuchi : 17 h. 57·6 m., S. 8° 11′ ; 5, 6. Both yellowish. Several orbits have been computed, with periods of 87 to 230 years. The longest period seems to be the best. Spectrum second type (F). Position : 257·7° ; 1·29″ (1900, Greenwich).

70 Ophiuchi : 18 h. 0·4 m., N. 2° 32′ ; 4·5, 6. Yellow, purplish. This well-known binary star was discovered by Sir W. Herschel in 1779, and has been well observed since that time. Numerous orbits have been computed, with periods of 73¾ to 98 years.

[1] *Monthly Notices*, R.A.S., December, 1900.

An orbit computed by the present writer in 1888 gave a period of 87·84 years, and this has been confirmed by the subsequent calculations of Burnham and Mann. See found 87·70 years. The orbital motion seems to be somewhat disturbed, possibly by the attraction of an invisible body. With a parallax of 0·162″ found by Krueger, Dr. See finds that the combined mass of the system is about 2·83 times that of the sun. Spectrum second type (K). Position: 246·9°; 1·61″ (1900, Greenwich).

99 Herculis: 18 h. 3·2 m., N. 30° 33′; 6, 11·7. Yellow, purple. For this close and difficult pair the present writer found a period of 53·55 years. See finds 54·5 years, and Aitken 63 years. The eccentricity is very high, about 0·78 according to See. Spectrum of the second type (F). Position: 309·5°; 0·98″ (1899, Greenwich).

ζ Sagittarii: 18 h. 56·3 m., S. 30° 1′; 3·9, 4·4. Both yellow. In the year 1886 the present writer computed an orbit and found a period of 18·69 years. Froley, in 1893, found 17·715 years, See finds 18·85, and Aitken 21·17 years. Position: 51·7°; 0·43″ ((1902, Tunis).

γ Coronæ Australis: 18 h. 59·6 m., S. 37° 12′; 5·5, 5·5. Both yellowish. Several orbits have been computed for this Southern binary star, with periods from 55 to 154·41 years. The latter period was computed by the present writer in 1892. Dr. See finds a very similar orbit, with a period of 152·7 years, and these orbits represent the measures satisfactorily. Position: 139°; 1·58″ (1901).

β Delphini: 20 h. 32·9 m., N. 14° 15′; 4, 6. Both yellowish. Discovered by Burnham in 1873. Several orbits have been computed, with periods ranging from 16·95 years, found by Celoria, to 30·91 years by the present writer. See finds 27·66 years. Spectrum second type (F 5 G). Position: 9·8°; 0·63″ (1900, Greenwich).

4 Aquarii: 20 h. 46·1 m., S. 6° 0′; 6, 7. Both yellow. Doberck finds a period of 129·8 years, and See 129 years. Spectrum of the first type (A). Position: 198·2; 0·24″ (1899, Greenwich).

δ Equulei: 21 h. 9·6 m., N. 9° 6′; 4·5, 5·0. Both yellow. A very rapid binary, for which Wroublewsky found a period of 11·48 years, and See 11·45 years. Hussey thinks, however, that the period is probably only one half of this, or about 5·7 years, and he has computed an orbit with this period.[1] Several revolutions have been described since its discovery by Otto Struve in 1852. Spectrum second type (F, Pickering).

κ Pegasi : 21 h. 40·1 m., N. 25° 11′ ; 4·3, 5·0. Both yellowish. Another very rapid binary, discovered by Burnham in 1880. Dr. See finds a period of 11·42 years. This and δ Equulei have the shortest periods at present known among binary stars, the components of which can be separately seen in large telescopes. In the so-called 'spectroscopic binaries' (see next section) the components are not visible—with the possible exception of Capella, which has been elongated at Greenwich. The spectrum of κ Pegasi is of the second type (F 5 G). (It is also a spectroscopic binary.) Position : 251·2° ; 0·14″ (1900, Greenwich).

85 Pegasi : 23 h. 56·9 m., N. 26° 34′ ; 6, 10. Yellowish, bluish. A close and difficult double star, discovered by Burnham in 1878. Schaeberle found a period of 22·3 years, Glasenapp 17·487 years, See 24·0 years, and Burnham 25·7 years. The pair have a large proper motion, for which the present writer found 1·221″ in the direction of position angle 141·2°. The spectrum is of the second type (E, Pickering). Position : 204·8° ; 0·75″ (1895).

Mr. Monck finds that, of the binary stars for which orbits have been computed, those showing the solar type of spectrum are much more numerous than those with the Sirian type. This would suggest that the solar stars are nearer to the earth than the Sirian.

Spectroscopic Binaries.—A new class of binary stars has been discovered in recent years by the aid of the spectroscope. These have been termed 'spectroscopic binaries,' and are supposed to consist of two component stars so close together that the highest powers of the largest telescopes fail to show them as anything but single stars. Indeed, the velocities indicated by the

[1] 'Publications of the Lick Observatory,' vol. v., 1901, p. 208. Recent measures by Aitken seem to confirm the short period found by Hussey.

spectroscope show that they must—in most cases, at least—be so close that the components will probably for ever remain invisible in the most powerful telescopes which could be constructed by human powers. By means of the spectroscope we can determine the rate in miles per second at which a star is approaching the earth or receding from it (as we explained under the head of Proper Motions). If, then, a star, apparently single in the telescope, consists in reality of two close companions revolving round each other in a short period, we can find in some cases the relative velocity of the components, although we may know nothing of the star's distance from the earth. For suppose the plane of the star's orbit to pass through the earth, or nearly so. Then when the line joining the components is at right angles to the line of sight, one of the stars will be rapidly approaching the earth and the other receding; consequently all the dark lines in the spectrum of the first star will be displaced towards the blue end of the spectrum, while those of the other will be shifted towards the red end. Each line will therefore appear double, and from the observed displacement the relative velocity can be easily computed. When the motion becomes perpendicular to the line of sight—that is, when the two stars are in a line with the earth—the motion to and from the eye ceases, and the lines again become single. We have, then, merely to find the times at which the lines appear single and double. As the lines will evidently double twice during each complete revolution, we must double the observed interval in order to obtain the period of revolution. The velocity and period thus found enable us at once to compute the actual dimensions of the system in miles, and its mass with reference to that of the sun, although the star's distance from the earth remains unknown. If one of the component stars is a dark body—as is the case in some of these systems—there will, of course, be only *one* set of lines in the spectrum, and the lines will then be merely shifted from their normal position, not doubled. This occurs in the case of Algol, the famous variable star, and in some other stars of the Algol type. These will be considered in the next chapter. Professor Campbell thinks that these spectroscopic binaries are probably quite as numerous in the sky as those in which the components are visible in the telescope.

The following are some stars which have been found double with the spectroscope :

The Pole Star : Period, 3·9683 d.=3 d. 23 h. 14 m. 21 s. The existence of a third star is suspected. The orbit is nearly circular, and about the size of the moon's orbit round the earth.

Capella (α Aurigæ) : Period, 104 days. Orbital velocity, about 18·6 miles a second. Attempts to see the star visually double with the great Lick telescope have failed, but several observers at the Greenwich Observatory have seen the star 'elongated' with the twenty-eight-inch refractor. The observed changes in the relative position of the components agree well with the period of 104 days found with the spectroscope. The orbit is nearly circular. Assuming that the plane of the orbit passes through the earth, Vogel finds that the mass of the system is about 2·3 times the sun's mass, and the distance between the components about 53,000,000 miles.[1] Professor Campbell finds that one component has a spectrum of the solar type, and the other seems to show the hydrogen line Hγ and the principal lines of iron.

δ Orionis : Period, 1·9 days. Orbital velocity, 42 miles a second. Spectrum B.

β Aurigæ : Period, 3·98 days. Velocity, 74 miles a second. Distance between components, about 8,000,000 miles. Mass of the system, about 5½ times that of the sun. Spectrum second type (G).

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[1] *Astrophysical Journal*, June, 1900, p. 389, footnote.

ζ Geminorum : A well-known variable star. Period of revolution, 10·15 days. Velocity, about 8 miles a second. The time of periastron passage does not coincide with the time of minimum brightness. Spectrum second type (G).

Castor (α Geminorum) : Period, 2·91 days. Companion a dark body. Mass of the system very small. Spectrum first type (A).

ξ Leonis : Period, 14·5 days. Velocity, 34 miles a second. Spectrum II (H).

ζ Ursæ Majoris (Mizar) : The brighter component of this wide double star was discovered to be a spectroscopic double at Harvard Observatory in 1889. The period was found to be about 104 days ; but Dr. Eberhard has since found a period of about 20·6 days.[1] Spectrum first type (A).

Spica (α Virginis) : Period, about 4 days. Velocity, 55 miles a second. Companion dark or nearly so. Vogel finds the mass of the system about 2·6 times the sun's mass, and the distance between the components about 6,500,000 miles. The system is approaching the earth at the rate of 9·2 miles a second. 'Taking the most probable view of the star's parallax, the angular separation of the stars would be 0·014″, a quantity far too small to be detected by the most powerful telescopes.' Spectrum first type (B 2 A).

ζ Centauri : Period, 8·024 days. Spectrum I (B 2 A, Peculiar, Pickering).

δ Libræ : This Algol variable is a spectroscopic binary with a high velocity. Spectrum A.

π Scorpii : Period, 1·571 days. Spectrum I (B 2 A, Pickering).

θ Draconis : Period, 9 days. Velocity, 15 miles a second. Spectrum F 8 G.

χ Draconis : Period, 281·8 days. Spectrum F 8 G.

μ Scorpii : Period, 1·45 days. Velocity, 142 miles a second. Mass about 14 times the sun's mass. Spectrum I (B 3 A, Peculiar, Pickering).

β Lyræ : The well-known variable star. Period, 12·91 days. Velocity, 112 miles a second. Keeler and Vogel agree that the supposed orbit is incompatible with the occurrence of eclipses—

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[1] *Astrophysical Journal*, June, 1901.

as in the case of Algol. Vogel, however, is 'convinced that β Lyræ represents a binary or multiple system, the fundamental revolutions of which in 12 d. 22 h. in some way control the light change, while the spectral variations, although intimately associated with the star's phases, are subject to complicated disturbances, running through a cycle perhaps measured by years.' G. W. Myers finds that the mass of the larger component is probably 21 times that of the sun, and that of the smaller 9½ times the solar mass. The mean density of the system is about the same as that of our atmosphere, so that the components are 'in a nebulous condition.' They revolve nearly in contact, and are probably surrounded by extensive atmospheres. Spectrum B 2 A (Composite).

η Aquilæ: Period, 7·18 days. Velocity, 12 miles a second. This is also a well-known variable star, and, like β Lyræ, the times of observed minima of light do not agree with the times of supposed eclipse in the computed orbit. Spectrum G.

κ Pegasi: This short-period binary star has been found to be also a close spectroscopic binary, but it is not possible to say at present which of the two components is the spectroscopic binary. Spectrum F 5 G.

ι Pegasi: Period, 10·2 days. Velocity, 27 miles a second. It is a suspected variable. Spectrum F 5 G.

δ Cephei: This well-known variable star is also a spectroscopic binary, with a period of 5·37 days, and, like η Aquilæ, the orbital motion does not account well for the light changes. Spectrum G.

η Pegasi: Period, 818 days. Velocity, 8·8 miles a second. Spectrum G.

λ Andromedæ: Period about 19·2 days. Velocity, about 5½ miles a second. Small mass. Spectrum II (K, Pickering).

Lacaille 3105: R.A. 7 h. 55·3 m., S. 48° 58′. Period, about 3 days. Magnitude, 4·50. One component slightly brighter than the other. Relative velocity about 380 miles a second! and mass about 70 times that of the sun. This is a very remarkable object, and its distance from the earth is probably very great. It is the Algol variable V Puppis (which see). Spectrum B 1 A.

ϕ Persei : Variable velocity from +24 kilometres to −12 kilometres. Spectrum B, Peculiar.

η Geminorum : Variable velocity from +14 kilometres to −25 kilometres. Spectrum Ma.

α Equulei : Variable velocity from −26 kilometres to −2 kilometres. Spectrum F 8 G, Composite.

Out of 350 stars examined by Professor Campbell, forty-one proved to be spectroscopic binaries, and he thinks that eventually 'it will be found that a star which is *not* a spectroscopic binary is a rare exception.'

CHAPTER III

VARIABLE STARS

Variable Stars—Classes of Variables—Temporary Stars—Long-Period Variables—Irregular Variables—Short-Period Variables—Algol Variables—Cluster Variables—Suspected Variables—Method of Observation.

Variable Stars.—To ordinary observation the light of the stars seems to be constant, and in most cases the brightness is—apparently, at least—invariable. There are, however, numerous exceptions to this rule, and these are known as 'variable stars'—a most interesting class of stellar objects. In some of these curious objects the light varies to a very considerable extent, the star being at times visible to the naked eye, and at others invisible except in a powerful telescope. In some the variation is small, in others irregular. Some have long periods between their maxima or minima of light; in others the period is only a few days, or even hours. Very few of the variable stars show any parallax or proper motion, and therefore probably lie at a great distance from the earth.

Classes of Variables.—The following classification of the variable stars has been proposed by Professor Pickering, of the Harvard College Observatory (U.S.A.):

CLASS I.—Temporary or new stars.

Class II.—Stars undergoing large variations of light in periods of several months.

Class III.—Irregularly variable stars undergoing but slight changes of brightness, as α Orionis (Betelgeuse).

Class IV.—Variable stars of short period, like δ Cephei, η Aquilæ, β Lyræ, etc.

Class V.—'Algol stars'—those which, like Algol, undergo at regular intervals a diminution of light lasting for a few hours only.

'Secular variation' is a term which has been applied to the supposed increase or decrease of light in certain stars in the course of ages. Some probable cases of this kind will be considered in the section on Suspected Variables.

Temporary or New Stars.—There are stars which at intervals in the history of astronomy have suddenly blazed out, sometimes with a brilliancy rivalling, or even surpassing, the brightest stars in the heavens, and, after remaining visible for some days or weeks (or in some cases months), have either entirely disappeared or become very faint objects in the telescope. In some cases the star has faded into a small planetary nebula. These extraordinary objects are termed *novæ*, or 'new stars.' They are also called 'temporary stars,' to express their short duration of brilliancy.

The following are some details of these remarkable objects. The first temporary star of which we have a reliable account is one recorded in the Chinese annals as having appeared in the year 134 B.C. in the constellation Scorpio. Pliny tells us that it was the sudden appearance of a new star which led Hipparchus to form his catalogue of stars, the first ever formed. As the date of Hipparchus' catalogue is 125 B.C., it seems very probable that the star referred to by Pliny was identical with that mentioned by the Chinese as having been seen nine years previously.

A temporary star is said to have appeared in the year 76 B.C.

between the stars α and δ in the 'Plough' (Ursa Major), but no details are recorded.

In the year 101 A.D. a small 'yellowish-blue' star is recorded in the well-known 'sickle in Leo,' but the description leaves its exact position uncertain.

In 107 A.D. 'a strange star' is recorded near δ, ϵ, and η Canis Majoris, and another in 123 A.D. near ι Herculis and α Ophiuchi.

A bright star is recorded in the Chinese annals as having appeared on December 10, 173, between the bright stars α and β Centauri in the Southern Hemisphere. It is said to have remained visible for seven or eight months, and is described as resembling a 'large bamboo mat'! The description, although very vague, seems to imply that it was of great brilliancy. Close to the spot indicated is a remarkable variable star, R Centauri,[1] which may possibly be identical with the star of the Chinese annals.

'Strange stars' are mentioned in the years 290, 304, and 369 A.D., but the accounts are very vague and their position uncertain. In the year 386 A.D. a new star was seen near λ, μ, and ψ Sagittarii. As the place indicated is near the position of a star which was observed by Flamsteed—65 Ophiuchi—now missing, it has been thought possible that Flamsteed's star may have been a return of the star recorded in the Chinese annals.

In the year 393 A.D. a strange star is recorded near μ^2 Scorpii, and another in 561 A.D. near α Crateris. A known variable and red star—R Crateris—lies close to the latter position.

In 829 A.D. the Chinese annals note a star somewhere near Procyon (α Canis Minoris).

An extraordinary star is recorded as having appeared near ζ Sagittarii in the year 1011 A.D., and another in 1203 near μ^2 Scorpii. The number of these objects recorded in this part of the sky is very remarkable.

Hepidannus mentions a star in Aries in 1012 as being of astonishing size and 'dazzling the eye'!

Temporary stars are mentioned as having been seen in

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[1] See section on Long-Period Variables.

1054 A.D. south-east of the star ζ Tauri, and in 1139 near κ Virginis, but the accounts are very vague.

In the year 1572 a very remarkable temporary star blazed out in Cassiopeia, and was well observed by Tycho Brahé, who has left us an elaborate account of it. According to Admiral Smyth, it was discovered by Schuler at Wittenberg on August 6, 1572, and was seen by Hainzel at Augsburg on August 7.[1] It seems to have been also seen by Lindauer at Winterthur on November 7, by Maurolycus on the following evening, and by Cornelius Gemma on November 9. Tycho Brahé, whose name is usually associated with the star, did not see it till November 11. It was then brighter than Jupiter, and equal to Venus at its maximum brilliancy. It was even visible in daylight in a clear sky. It slowly diminished in brightness, and in March, 1574, had completely disappeared—at least to the naked eye. It was situated about 1½° north of κ Cassiopeiæ, the faintest stars in the well-known 'Chair.' Within one minute of arc of the position given by Tycho Brahé is a star of about the eleventh magnitude, which is said to show signs of variable light. The exact position of this wonderful *nova*, reduced to 1900, is R.A. 0 h. 19 m. 15 s., N. 63° 35·5′.

Another very brilliant new star was observed by Kepler in October, 1604, in Ophiuchus, and described by him in his work 'De Stella Nova in Pede Serpentarii.' The planets Mars, Jupiter, and Saturn were near each other in this region of the heavens (a few degrees south-east of the star η Ophiuchi), and on the evening of October 10, Brunowski, one of Kepler's pupils, noticed that a new and very brilliant star was added to the group. When first seen it was white and exceeded in brilliancy Mars and Jupiter, and was even thought to rival Venus in brightness! It slowly diminished, and in six months was not equal in lustre to Saturn. In March, 1606, it had entirely disappeared. It was also seen by Galileo. Its position, reduced to 1900, is in R.A. 17 h. 24 m. 38 s., S. 21° 23·7′.

In the year 1612 a new star is said to have appeared in Aquila. Klein thinks that this is identical with one mentioned by the Chinese in 1609.

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[1] 'Bedford Catalogue,' p. 55.

In 1670 a star of the third magnitude was observed by Anthelm near β Cygni. It remained visible for about two years, and increased and diminished several times before it finally disappeared. A star of the eleventh magnitude has been observed near its place at Greenwich Observatory, and variation was suspected in this small star by Hind and others. There is a known variable star—S Vulpeculæ—near the place; but, according to Hind, 'this variable is distinct from Anthelm's.' The position of Anthelm's star for 1900 is R.A. 19 h. 43 m. 28 s., N. 27° 42′.

A small temporary star was observed by Hind in Ophiuchus on April 28, 1848. When first noticed it was about the fifth magnitude, but very soon faded to tenth or eleventh magnitude. This curious object has become very faint in recent years. In 1866 it was twelfth magnitude, and in 1874 and 1875 not above thirteenth magnitude. Its position for 1900 is R.A. 16 h. 53 m. 54 s., S. 12° 44·4′.

A new star was discovered by Pogson, May 28, 1860, in the globular cluster 80 Messier in Scorpio. When first seen it was 7·6 magnitude, and bright enough to obscure the cluster in which it was apparently situated. On June 10 it had nearly disappeared, and the cluster again shone with great brilliancy and with a condensed centre. Pogson's observations were confirmed by Auwers and Luther. It (or another star in the cluster) was again seen as eleventh magnitude by Pogson on June 9, 1863. On February 10, 1864, he estimated it at ninth magnitude, and on March 5 9.3, and it afterwards rapidly faded again.[1] Its position for 1900 is R.A. 16 h. 11 m. 5 s., S. 22° 43·6′. Near the cluster are two known variable stars, R and S Scorpii.

A very interesting temporary star, sometimes spoken of as 'the Blaze Star,' suddenly appeared in Corona Borealis in May, 1866. It was first seen by Birmingham, at Tuam, Ireland, about midnight on the evening of May 12, when it was about the second magnitude, and equal to Alphecca, the brightest star in the well-known 'coronet.' It was shortly afterwards noticed by several observers in various parts of the world. It seems to have blazed out very suddenly, as Schmidt, the

[1] *Astrophysical Journal*, 1902, April 16, p. 127.

Director of the Athens Observatory, stated that he was observing the region about two and a half hours before Birmingham's discovery, and felt certain that no star of even the fifth magnitude could possibly have escaped his notice. The star rapidly diminished in brightness, and on May 24 of the same year had faded to 8·5 magnitude. It afterwards increased to about seventh magnitude, but quickly diminished again. It was soon discovered that the star was not really a new one, but had been previously observed by Schönfeld at Bonn in 1855 and 1856, and rated as 9·5 magnitude on both occasions. A few days after its discovery its light was examined by Dr. Huggins with the spectroscope, and it showed the bright lines of hydrogen gas in addition to the ordinary stellar spectrum. During the years 1866 to 1876 Schmidt detected variations of light which seemed to show a certain regularity, and he deduced a probable period of about 94 days. This was confirmed by Schönfeld, who observed changes in the star's light from about the seventh to the ninth magnitude. It would therefore seem to be an irregular variable star, and not a true *nova*. It is situated a little south of ϵ Coronæ Borealis, and its position for 1900 is R.A. 15 h. 52 m. 19 s., N. 26° 12·2′.

On the evening of November 24, 1876, a remarkable temporary star was discovered by Schmidt at Athens, near ρ Cygni. When first seen it was about the third magnitude. Schmidt observed the region on several nights between November 1 and 20, and was certain that no star of even the fifth magnitude could have escaped his notice. Between November 20 and 24 the sky was cloudy, so that the exact time of its appearance is unknown. It rapidly diminished in brightness, and on November 30 had faded to the fifth magnitude. It afterwards decreased very regularly to August, 1877. It was spectroscopically examined a few days after its discovery, and its spectrum showed bright lines similar to the star in Corona Borealis. In September, 1877, it was found to have faded into a small planetary nebula. It was only fifteenth magnitude in September, 1885, and about 15·5 in 1902. It is now known as Q Cygni, and its position for 1900 is R.A. 21 h. 37 m. 47 s., N. 42° 23·1′.

Towards the end of August, 1885, a small star made its appearance close to the nucleus of the Great Nebula in Andromeda

(Messier 31). The new star was independently discovered by several observers. Its magnitude was estimated 6·5 by Engelhardt on September 1, and 7·3 on September 2. Mr. Maunder at Greenwich Observatory found its spectrum 'of precisely the same character as that of the nebula; *i.e.*, it was perfectly continuous, no lines, either bright or dark, being visible, and the red end was wanting.' Dr. Huggins, however, on September 9 thought he could see from three to five bright lines in its spectrum. The star gradually faded away, and on February 7, 1886, was estimated only sixteenth magnitude with the twenty-six-inch refractor at the Washington Observatory. Professor Asaph Hall found 'no certain indications of any parallax.' Auwers pointed out the similarity between this outburst and the new star of 1860 in the cluster 80 Messier, and he thought it very probable that both phenomena were due to physical changes in the nebulæ in which they occurred.

A small temporary star of the ninth magnitude appeared in the constellation Perseus in 1887. It was found by Mrs. Fleming on photographs of stellar spectra taken at Harvard Observatory.

A remarkable and interesting temporary star was discovered in January, 1892, by Dr. Anderson, in Auriga. He announced its discovery to Dr. Copeland, of the Royal Observatory, Edinburgh, on February 1, but seemed certain that he had seen it on the morning of January 24 (but mistook it for 26 Aurigæ). It was then about fifth magnitude. After this announcement was published an examination was made of photographic plates taken at the Harvard Observatory, and it was found on photographs taken between December 16, 1891, and January 31, 1892. These photographs showed that the star was fainter than the eleventh magnitude on November 2, 1891, and Professor Pickering says it 'probably attained the seventh magnitude within a day or two of December 2, and the sixth magnitude on December 7. The brightness increased rapidly until December 18, attaining its maximum about December 20, when its magnitude was 4·4. It then began to decrease slowly, with slight fluctuations until January 20, when it was slightly below the fifth magnitude. All these changes took place before its discovery, so that it escaped observation nearly two months.

During half of this time it was probably brighter than the fifth magnitude.' The star rose to another maximum of light in February, for on February 14, when first seen by the present writer, he estimated it 4·55 magnitude. After this it rapidly diminished, and on March 18 of the same year it was about ninth magnitude. On April 1 it had faded to about the fifteenth. In August, 1892, it brightened up again to about ninth magnitude, and then diminished to about tenth or eleventh, and remained in this state to the end of 1894. It then slowly diminished, and in February, 1901, it was found to be a very faint and minute nebula. Soon after its discovery its spectrum was found to contain bright lines accompanied by dark lines. The observed shift in these lines indicated enormous velocities and suggested the theory of a collision between two dark bodies. However this may be, there seems to be no doubt that it has now—like several other temporary stars—changed into a planetary nebula. Its position for 1900 is R.A. 5 h. 25 m. 34 s., N. 20° 22·2′.

Another small *nova* of about the seventh magnitude appeared in the Southern constellation Norma in 1893. The spectrum was similar to that of Nova Aurigæ, and, like that star, it seemed to have faded into a planetary nebula. Its position for 1900 is R.A. 15 h. 22 m. 11 s., S. 50° 13·9′.

Another small temporary star of about the eighth magnitude was discovered by Mrs. Fleming in the Southern constellation Argo. It seems to have appeared between March 5 and April 8, 1895. On July 1, 1895, it had diminished to the eleventh magnitude. The spectrum seems to have been the same as that of the new stars in Auriga and Norma. Another object of the same kind (?) was also found by Mrs. Fleming on photographs of the constellation Centaurus. It was about the seventh magnitude at its brightest, and appeared some time between June 14 and July 8, 1895. It was observed visually on December 16, 1895, by Professor O. C. Wendell and had then faded to the eleventh magnitude. The spectrum was *not* similar to those of the temporary stars in Auriga, Norma, and Argo. It was closely north-east of the nebula N.G.C. 5253. On December 22 and 29, 1895, Professor Campbell found that the spectrum was continuous but peculiar, and quite unlike that of the nebula near it. On June 11, 1896, Professor Hussey found the star 14·4 magnitude, and surrounded by 'a faint irregular nebula which seemed to extend continuously to the nebula south preceding.' On July 9 it had faded to the sixteenth magnitude, and the nebula surrounding it was 'seen to be continuous with the adjacent nebula.' On January 4, 1897, Hussey failed to find the star, and it must have been then below the sixteenth magnitude.[1] Chandler is of opinion, however, that the star may possibly be merely a long-period variable, with a period of 374 days, or 'irregular.' Its position for 1900 is R.A. 13 h. 34 m. 17 s., S. 31° 7·6′.

Early in the year 1898, or possibly towards the end of 1897, a new star appeared in the constellation Sagittarius. It was found by Mrs. Fleming on photographic plates taken at Harvard in March and April, 1898. These showed that it was about 4·7 magnitude on March 8, and had diminished to 8·4 on April 29. It was observed with the telescope by Wendell on March 13, 1899, and estimated 11·37 magnitude. A photograph of the spectrum taken on April 19, 1898, shows the hydrogen lines bright, and some other lines which seemed to be identical with lines in the spectrum of Nova Aurigæ. When observed by Wendell, its light was found to be nearly monochromatic (that is, of nearly one colour), showing 'the chief nebular line' and a faint continuous spectrum. It would, therefore, seem that this star, like other new stars, has 'changed into a gaseous nebula.' Its position for 1900 is R.A. 18 h. 56 m. 12·8 s., S. 13° 18′ 13″.

Another small *nova*, also discovered by Mrs. Fleming, appeared in April, 1899, in the constellation Aquila, a little south-west of the star δ Aquilæ. It was about seventh magnitude on April 21, 1899, tenth magnitude on October 27, 1899, and in July, 1900, it was found to be 'a nebula of the twelfth magnitude.' Its place for 1900 is R.A. 19 h. 15 m. 16 s., S. 0° 19·2′.

The discovery of so many of these small temporary stars in the last few years suggests that the phenomenon may not be so rare as is generally supposed. But unless a new star became clearly visible to the naked eye it might very easily escape detection.

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[1] *Astrophysical Journal*, April, 1897.

Lastly we come to the very remarkable and brilliant new star—the brightest of modern times—which suddenly blazed out in the constellation Perseus on the night of February 21, 1901. It was discovered by Dr. Anderson (the discoverer of Nova Aurigæ) at Edinburgh about 2.40 on the morning of February 22 as a star of about 2·7 magnitude, and was independently detected on the following evening (February 22) by several observers, including the present writer. It rapidly increased in brilliancy, and on the evening of February 23 it was slightly brighter than Capella, and was then probably the brightest star in the Northern Hemisphere! Its rise in brightness must have been very rapid. Three German astronomers—Grimmler, Plassman, and Schwab—stated that they were observing the region on February 21 from 7 to 10.30 p.m., and think that no star brighter than the third magnitude could possibly have escaped their notice. A photograph of the region taken by Mr. Stanley Williams, the well-known English astronomer, on February 20, about 11 p.m., or only twenty-eight hours before the discovery of the *nova* by Dr. Anderson, shows no trace of the new star, although stars to about the eleventh magnitude are clearly visible. After February 23 the new star gradually diminished in brightness, and on the night of February 25 it was reduced to about the first magnitude. On March 1 it had decreased to about the second, and about March 6 to the third. From that date it faded with some small fluctuations of light until March 18, when it had descended to about the fourth magnitude. From that date a series of the most remarkable fluctuations of light set in. On the evening of March 19 it had fallen to a little below the fifth magnitude. On March 20 it had risen to 3·5, and on the 22nd it was again below fifth magnitude. It was again about fourth magnitude on March 23, and below five on March 25. It again rose to above four on March 26, and these curious fluctuations continued with more or less regularity, and with a longer period of variation, until the third week in May, when the star became so low on the Northern horizon, and the twilight so strong, that observations became very difficult. During the month of June the observations show considerable fluctuations, and to a smaller extent in July also. In August the variation of light was small, the estimates of magnitude ranging from 5·7 to 6·5. During September and October, 1901, the star's light seemed to fade slowly, with no violent fluctuations, from about 6·2 to 6·7. At the end of the year it had fallen to about seventh magnitude. In the beginning of March, 1902, it had faded to the eighth magnitude; in June, 1902, to the ninth, and in November, 1902, to about the tenth magnitude.

When the new star was first seen by Dr. Anderson, he thought its colour was bluish-white, and it remained of a white or slightly yellowish colour on February 23 and 24. It was of a pale yellow on February 25 and 26, and became orange at the beginning of March. During the remarkable oscillations of brightness the colour seems to have been orange at maximum and red at minimum light. Early in 1902 Professor Barnard found it 'greenish-white.'

According to Professor Pickering, the spectrum of the new star was on February 22 and 23 of the 'Orion type,' 'nearly continuous, with narrow dark lines.' On February 24 there was a remarkable change, the spectrum having then become like that of other new stars—that is, crossed by dark and bright bands, the principal dark lines being bordered by bright lines on the red side of the spectrum. The observed displacement of the hydrogen lines from their normal position in the spectrum seemed to indicate a relative velocity of 700 to 1,000 miles a second, thus suggesting the collision of two bodies with high velocities. But these enormous velocities of colliding bodies seem to be contradicted by the fact that measures of the dark lines of calcium and sodium by Adams, Campbell, Stebbins, and Wright in America indicate a velocity in the line of sight of only some three miles a second. The observed high velocity may have been, however, due to an outburst of hydrogen gas from the body of the star. Remarkable changes were also observed in the spectrum during the sudden fluctuations in the star's light which took place in March, April, and May, 1901. An examination of photographs of the star's spectrum taken at the Harvard Observatory in July, 1901, showed that, like other new stars, it was slowly changing into a gaseous nebula, 'the chief nebular line' being very bright. The nebular spectrum became more marked in August and September, 1901.

In September, 1901, Dr. Max Wolf, while examining the new star, discovered a faint trace of nebula a little south of the *nova*. As his telescope was not powerful enough to deal with this faint object, he suggested that it should be photographed with a large telescope. This was done by Mr. Ritchey at the Yerkes Observatory (U.S.A.) with a two-feet reflector on September 20, 1901, and the photograph showed a mass of nebulous matter of great extent, and of apparently a spiral form surrounding the *nova*. This interesting discovery was confirmed by Mr. Perrine at the Lick Observatory by photographs taken on November 7 and 8, and, from a comparison of his plates with the photograph taken by Ritchey, he found that some of the principal condensations of the nebula were apparently moving with an enormous velocity. Perrine's startling result was confirmed by Ritchey. This unheard-of motion—about eleven minutes of arc per annum —in a sidereal object seemed to preclude the idea of a *real* velocity of the nebulous matter in space, and the theory was suggested by Professor Kapteyn and Dr. W. E. Wilson that the nebulous matter shone merely by reflected light from the new star. Assuming this to be the case, calculation showed that the observed motion might be accounted for by supposing that the new star had a parallax of about 0·011, or a 'light journey' of about 296 years! Perrine afterward announced that he had found a photograph taken on March 29, 1901, on which some of the nebulosity was very visible. This 'reflexion theory' is supported by Hinks and Seeliger, but others do not agree.

Attempts to measure the distance of this wonderful object from the earth have not proved very satisfactory, and its distance is doubtless very great. Measures made from small stars near it by Dr. Hartwig at Bamberg and Dr. Chase at Yale College Observatory show a negative parallax, which would imply that the *nova* lies further from the earth than the comparison stars. Bergstrand, however, finds from photographic plates an absolute parallax of 0·033".[1] This result would give a journey for light of about ninety-nine years.

On one of the earlier photographs of the region taken at the Harvard Observatory a very faint star was found by Father Zwack very close to the place of the *nova*. From measurements

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[1] *Astronomische Nachrichten*, No. 3,834.

of photographs taken in the years 1890 to 1900 Professor Pickering finds that this small star was variable to the extent of about one magnitude, and that its position closely agrees with that of the new star. The same small star was also found by M. S. Blajko on a photograph taken by him on January 30, 1899. Professor Pickering says: 'We may therefore conclude that a star whose light varied from the thirteenth to the fourteenth magnitude was visible for several years within one or two seconds of arc of the *nova*, the difference in position being less than the errors of measurement.'[1]

The position of the *nova* for 1900 is R.A. 3 h. 24 m. 24 s., N. 43° 33′ 39″. It lies between the stars κ and ν Persei, a little nearer to the latter star.

Several theories have been advanced to explain the phenomena of temporary stars, but none of them are very satisfactory. The rush of a dark, or nearly dark, body through a gaseous nebula is perhaps the most probable cause of these outbursts. The friction produced by the rapid motion of a body through a nebulous mass would, of course, produce enormous heat, and this intense heat might, again, produce an explosion of gases imprisoned in the interior of the dark, or nearly dark, body. Both causes may possibly combine to produce the observed phenomena. A collision between two dark bodies would produce a somewhat similar result, but such an event is evidently not so probable as the passage of a dark body through a gaseous nebula.

Long-Period Variables.—In this class of variable stars the variation of light is generally very large—usually several magnitudes—and the length of the period considerable, ranging from about 90 to 610 days from maximum to maximum. Several seem to have periods of about a year. There are a large number of these long-period variables known.

The following are among the most remarkable and interesting of the long-period variables. Most of them can be observed

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[1] Harvard College Observatory *Circular*, No. 66, October 31, 1902.

at maximum with an opera-glass. They are given in order of right ascension. The positions are for 1900:

T Cassiopeiæ: R.A., 0 h. 17 m. 49 s., N. 55° 14·3′. Between β and λ Cassiopeiæ, nearer the latter star. Discovered by Krueger in 1870. It varies from 7 to 8 magnitude at maximum to 11 to 12 at minimum. Mean period about 445 days, but with some irregularities. The star is red, and Grover has seen it 'surrounded by a ruddy haze.' A maximum (magnitude 7·2) was observed by Grover, August 8, 1901 (interval since last maximum 437 days), and another (7·4 magnitude), October 30, 1902 (interval 448 days).

R Andromedæ: 0 h. 18 m. 45 s., N. 38° 1·4′. Closely north of ρ Andromedæ. Discovered at Bonn, 1858. Maximum 5·6 to 8·6; below 12·8 at minimum. Mean period, about 411 days. A maximum was observed by Dr. Kelly at Kingstown, Ireland, on December 15, 1901. The spectrum is a remarkable one of the third type. In September, 1889, Espin found the F line very bright.

S Cassiopeiæ: 1 h. 12 m. 18 s., N. 72° 5·1′. Discovered at Bonn, 1861. A little to the west of the star 40 Cassiopeiæ. Max. 6·7 to 8·6; min. below 13. Period about 610 days, one of the longest known. Peek saw a bluish nebulosity round the star in March, 1900. A maximum (7·55 magnitude) was observed at Harvard on September 23, 1901. Espin found the F line very bright on November 28, 1889.

ο (Mira) Ceti: 2 h. 14 m. 18 s., S. 3° 25·7′. A very remarkable and interesting variable star. Discovered by Fabricius in 1596. It varies from 1·7 to 5 magnitude at maximum to 8 to 9·5 at minimum. Mean period, about 331 days, but with irregularities. This is perhaps the most interesting variable in the heavens. Its brightness at maximum is very variable. At the maximum of 1779 Wargentin found it equal to Aldebaran on October 30, and on November 2 he thought it had further increased in brightness. On the other hand, Heis found it only fifth magnitude at the maximum of November 7, 1868. At the minimum it never descends below 9·5 magnitude, so that it always remains visible in a three-inch telescope. At the minimum of December, 1901, it was estimated 8·75 by Nijland (*Ast.*

Nach., No. 3,795). The following maxima have been observed in recent years :

Date.	*Magnitude.*	*Observer.*
1897, December 2 ...	3·4	Flanery.
1898, October 5 ...	2·78	Harvard.
1898, October 9 ...	2·6	Gore.
1898, October 15 ...	2·6	Flanery.
1899, September 5...	3·53	Harvard Observatory.
1899, September 23	4·0	Flanery.
1900, July 31 ...	3·26	Harvard Observatory.
1901, July 14 ...	4·33	Harvard Observatory.

The hydrogen lines of the spectrum were seen bright by Secchi in 1869 and by Espin in 1888.

U Ceti : 2 h. 28 m. 56 s., S. 13° 35·2′. Discovered by Sawyer in 1885. Max. 6·8 to 7·3; min. about 12. Period about 236 days. A maximum was observed February 1, 1901.

R Trianguli : 2 h. 30 m. 59 s., N. 33° 49·8′. Discovered by Espin, 1890. Max. 5·3 to 7·1 ; min. 11·7. Mean period about 268 days. A maximum (5·30 magnitude) was observed on January 2, 1901.

R Horologii : 2 h. 50 m. 33 s., S. 50° 17·9′. Discovered at Harvard, 1892. Max. 4 to 6·2 ; min. 10·7. A very remarkable variable. Period about 408 days. A maximum (4 magnitude) was observed July 10, 1900.

T Eridani : 3 h. 50 m. 57 s., S. 24° 19·5′. Discovered at Harvard, 1895. Max. 7·2 ; min. 11. Mean period, 253 days (H. M. Parkhurst).

R Reticuli : 4 h. 32 m. 30 s., S. 63° 14·2′. Discovered by the Indian astronomer Ragoonathi Chari, in 1867, at the Madras Observatory (confirmed by Roberts). Max. 7·8 to 8·5; min. below 13. Period 280 days.

R Leporis : 4 h. 55 m. 3 s., S. 14° 57·4″. Discovered by Schmidt in 1855. Max. 6 to 7 ; min. about 8·5. Period, 436 days, but with an inequality. This is Hind's 'crimson star.' It is very red—9·4 on a scale of 0 to 10.

R Aurigæ : 5 h. 9 m. 13 s., N. 53° 28·4′. About 3° north-east of 9 Aurigæ. Discovered at Bonn, 1862. Max. 6·5 to 7·8 ; min. 12·5 to 12·7. Period, about 460 days, but with irregularities. There is a 'stand still' in the light curve at about 9 magnitude from two to four months before maximum, and the star remains at this brightness for about 48 days. The spectrum is a fine one of the third type. A maximum was observed by Grover (6·9 magnitude) on July 23, 1900, and another (7·2 magnitude) October 24, 1901 (interval 458 days).

U Orionis : 5 h. 49 m. 53 s., N. 20° 9·5′. Discovered by Gore on December 13, 1885. It was at first thought to be a temporary star or *nova*, but afterwards proved to be a long-period variable. Max. 6 to 7·5 ; min. below 12. Mean period about 375 days. A maximum (6·1) was observed by Grover on April 13, 1901, and at Harvard on April 26, 1901 (magnitude 6·36). Krueger calls its 'colour a peculiar copper red'[1] (8·4 on a scale of 0 to 10). It has a fine spectrum of the third type.

η Geminorum : 6 h. 8 m. 51 s., N. 22° 32·2′. Discovered by Schmidt in 1865. Max. 3·2 ; min. 3·7 to 4·2. Mean period about 231 days. The star was found to be a close and difficult double by Burnham—a feature very unusual among long-period variable stars. Professor Campbell finds a variable velocity in the line of sight.

V Monocerotis : 6 h. 17 m. 41 s., S. 2° 8·7′. Discovered by Schönfeld in 1883. Max. 6·3 to 6·9 ; min. about 10·7. Period, about 332 days.

R Geminorum : 7 h. 1 m. 20 s., N. 22° 51·5′. About 3° west of δ Geminorum. Discovered by Hind in 1848. Max. 6·6 to 7·8 ; min. below 13. Period, about 370 days. According to Schönfeld, the light curve is very variable at maximum, when the star often remains for a week without any perceptible change. Vogel saw the hydrogen lines of the spectrum bright in February, 1869. A maximum was observed by M. Esch about middle of September, 19 1.

L_2 Puppis : 7 h. 10 m. 29 s., S. 44° 29·8′. Discovered by Gould in 1872. Max. 3·4 to 4·6 ; min. 5·8 to 6·2. Period, about 140 days. Variation rapid at maximum and comparatively slow at minimum. Red in all phases of its light, and especially so at minimum. It has a splendid spectrum of the third type.

U Geminorum : 7 h. 49 m. 10 s., N. 22° 15·8′. Discovered by

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[1] *Astrophysical Journal*, August, 1895, p. 148.

Hind in 1855. Max. 8·9 to 9·7; min. below 13. Mean period, about 86 days, but with large irregularities. Although this star cannot be observed without a telescope, it is inserted here, as being, perhaps, the most wonderful variable star in the heavens. For most of its period the star remains about the thirteenth magnitude. It then suddenly brightens, and after remaining near a maximum for a few days it diminishes again in a few hours. Sometimes it rises to a maximum with astonishing rapidity. In February, 1869, it was observed by Schönfeld to increase three magnitudes in twenty-four hours! Some marvellous fluctuations of light were observed by Pogson. On March 26, 1856, he says: 'The variable subject to strange fluctuations at intervals of six to fifteen seconds, quite to the extent of four magnitudes; when the adjacent stars were quite steady and not at all twitching, like the variable. At times it surpassed the [comparison] star 8·9; at others it had quite vanished. A new phenomenon to me! Watched it for half an hour, with powers 54, 65, and 95, on the equatorial' (at Oxford, England).[1] On the following evening (March 27, 1856) he says: 'Light very unsteady, but not subject to such pulsations as were seen last night.' On April 16, 1866, Pogson found it 'of the thirteenth magnitude. The following day it had attained its maximum brightness (ninth to tenth magnitude)'![1] The spectrum is said to be continuous. At a maximum, in 1858, Baxendell found that this extraordinary object 'had a somewhat hazy or nebulous appearance.'

R Cancri: 8 h. 11 m. 3 s., N. 12° 2·0′. About 3° north of β Cancri. Discovered by Schwerd in 1829. Max. 6·0 to 8·3; min. below 11·7. Period, about 353 days, but lengthening. A maximum (7·87 magnitude) was observed at Harvard Observatory about December 14, 1900.

R Carinæ: 9 h. 29 m. 44 s., S. 62° 20·8. Between κ and l Carinæ. Discovered by Gould in 1871. Max. 4·3 to 5·7; min. 9·2 to 10. Mean period, about 309·7 days. A very interesting variable. Roberts finds that the period varies from 305·8 to 312·8 days, and that a full cycle is completed in thirty-seven

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[1] Quoted from Mr. Pogson's Journal by Mr. Joseph Baxendell in the *Astrophysical Journal*, April 16, 1902, p. 127.

or thirty-eight years.[1] He observed a maximum on March 20, 1901. The star is red.

R Leonis Minoris: 9 h. 39 m. 35 s., N. 34° 58·3′. Discovered by Schönfeld in 1863. Max. 6·1 to 7·8; min. 13. Mean period, about 370·5 days, but subject to irregularites. Spectrum third type.

R Leonis: 9 h. 42 m. 11 s., N. 11° 53·6′. Closely south of the star 19 Leonis. Discovered by Koch in 1782. Max. 5·2 to 6·7; min. 9·4 to 10. Mean period, about 313 days. A very interesting variable and easily found with an opera-glass at maximum. It is red in all phases of its light, and has a fine spectrum of the third type. A maximum (5·6 magnitude) was observed by Flanery, April 13, 1900, and another at Harvard Observatory (6·10 magnitude), February 27, 1901. Espin saw the hydrogen lines bright in March, 1889.

S Carinæ: 10 h. 6 m. 11 s., S. 61° 3·6′. Discovered by Gould, 1871. Max. 5·8 to 6·6; min. 9 to 9·2. Mean period, 149·1 days. Increase of light slower than decrease—an unusual feature among variable stars. The star is reddish.

R Ursæ Majoris: 10 h. 37 m. 34 s., N. 69° 18·0′. About 3° north of 38 Ursæ Majoris. Discovered by Pogson in 1853. Max. 6 to 8·2; min. 12·6 to 13·2. Mean period, about 302 days. The star 'rises with astonishing rapidity to the maximum, but fades away very slowly.' The spectrum is of the third type. A maximum (7·6 magnitude) was observed by Grover on March 16, 1901, and at Harvard (7·37 magnitude) on March 23, 1901, and another by Grover (7·5 magnitude) on January 20, 1902 (interval 310 days), and (7·7 magnitude) on October 30, 1902 (interval 283 days). At the maximum of 1901 Peek found that its colour changed in two months 'from deep dull ruddy to nearly white.'

R Corvi: 12 h. 14 m. 27 s., S. 18° 42·0′. About 3½° south-east of γ Corvi. Discovered by Karlinski in 1867. Max. 6·8 to 7·7; min. below 11·5. Period, 318·5 days. Increase of light quicker than decrease. Spectrum of the third type.

T Ursæ Majoris: 12 h. 31 m. 50 s., N. 60° 2·3′. Discovered

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[1] *Monthly Notices*, R.A.S., June, 1901.

by Hencke in 1856. Max. 6 to 8·5; min. 12·2 to 13. Mean period, 257 days. Spectrum of the third type. A maximum (7·9 magnitude) was observed on August 15, 1901, by Grover, who says: 'This was the faintest maximum of this star since 1886. The light at the three previous maxima was 6·3 magnitude.' He observed another maximum on May 23, 1902, when the brightness was again 6·3 magnitude (interval 281 days).

R Virginis: 12 h. 33 m. 26 s., N. 7° 32·3′. Discovered by Harding in 1809. Max. 6·5 to 8·0; min. 9·7 to 11·0. Period, about 145½ days, but with some irregularities. A maximum (7·10 magnitude) was observed at Harvard, May 15, 1901.

S Ursæ Majoris: 12 h. 39 m. 34 s., N. 61° 38·4′. Discovered by Pogson in 1853. Max. 6·7 to 8·2; min. 10·2 to 11·5. Period, about 226·5 days. Maxima were observed by Grover (7·7 magnitude) on May 24, and (7·6 magnitude) on December 27, 1901 (interval 217 days), and (7·7 magnitude) on August 8, 1902 (interval 224 days).

R (v) Hydræ: 13 h. 24 m. 15 s., S. 22° 45·9′. Discovered by Maraldi in 1704. Max. 3·5 to 5·5; min. 9·7. Mean period, 427 days, but with irregularities. A remarkable and interesting variable. The period has diminished since its discovery, having been about 500 days in 1708, 487 days in 1785, 461 days in 1825, and 437 days in 1870. The minimum occurs about 190 days before the maximum. The spectrum is a very fine one of the third type, which Dunér describes as 'd'un beauté tout a fait extraordinaire,' the bands being extremely wide and perfectly black. At the maximum of 1889 Espin found the hydrogen lines bright in the spectrum. The star is reddish. Maxima were observed by Flanery on May 5, 1897 (4 magnitude), and July 4, 1898 (4·9 magnitude).

S Virginis: 13 h. 27 m. 47 s., S. 60° 40·8′. Between the stars 72 and 81 Virginis. Discovered by Hind in 1852. Max. 5·7 to 8·0; min. 12·5. Mean period, 376·4 days. Spectrum of the third type. A maximum (6·8 magnitude) was observed by Flanery on July 22, 1899.

T Centauri: 13 h. 36 m. 2 s., S. 33° 5·5′. Discovered by Markwick in 1894. Max. 5·3 to 6; min. 7·2 to 9·1. Mean period, 90·4 days. An interesting variable star.

R Canum Venaticorum: 13 h. 44 m. 39 s., N. 40° 2·4′. Discovered by Espin in 1888. Max. 6·1 to 7; min. 11·5. Period, 338 days.

R Centauri: 14 h. 9 m. 22 s., S. 59° 26·9′. About 2° east of β Centauri. A remarkable variable discovered at Cordoba in 1871. Max. 5·2 to 6·0; min. 8·7 to 13. Mean period, about 569 days. There are two maxima and two minima. 'The two maxima follow one another at intervals of 204 and 364 days respectively' (Roberts, *Monthly Notices*, R.A.S., March, 1901). The star is red.

R Camelopardalis: 14 h. 25 m. 6 s., N. 84° 17·1′. Discovered by Hencke in 1858. Max. 6·9 to 8·6; min. 11·8 to 13·5. Mean period, 269·5 days. Maxima were observed by Grover on March 1, 1900 (6·9 magnitude), and July 28, 1901 (7·6 magnitude).

V Boötis: 14 h. 25 m. 42 s., N. 39° 18·5′. Discovered by Dunér in 1884. Max. 6·7 to 7·6; min. 9 to 10·5. Mean period, 256 days. A maximum was observed by H. M. Parkhurst, September 5, 1901 (7·22 magnitude). The star is D.M. + 39°, 2773. Spectrum, third type.

R Boötis: 14 h. 32 m. 47 s., N. 27° 10·2′. A little west of 34 Boötis. Discovered at Bonn in 1858. Max. 5·9 to 7·8; min. 11·3 to 12·2. Mean period, 223·4 days. A maximum (6·85 magnitude) was observed at Harvard about April 11, 1901.

S Coronæ: 15 h. 17 m. 19 s., N. 31° 43·6′. Discovered by Hencke in 1860. Max. 6·1 to 7·8; min. 11·9 to 12·5. Mean period, 360·8 days. Spectrum of third type. At the minimum it has been observed by Peek apparently obscured by nebulosity. A maximum (6·8 magnitude) was observed by Grover March 22, 1901.

R Serpentis: 15 h. 46 m. 5 s., N. 15° 26·3′. Between β and γ Serpentis. Discovered by Harding in 1826. Max. 5·6 to 7·6; min. 13. Mean period, 357·6 days. Spectrum of the third type. A maximum was observed by H. M. Parkhurst on September 9, 1901 (6·46 magnitude), and another by Dr. Kelly about August 12, 1902.

X Herculis: 15 h. 59 m. 39 s., N. 47° 30·8′. Discovered by Gore in 1890. Max. 5·9 to 6·3; min. 6·8 to 7·2. Mean period, about 92½ days, but with inequalities. The star is very reddish.

U Herculis: 16 h. 21 m. 22 s., N. 19° 7·2′. Discovered by

Hencke in 1860. Max. 6·6 to 7·9; min. 11·4 to 12·7. Mean period, 409 days. A maximum was observed by M. Esch January 10, 1902 (7·9 magnitude).[1]

R Draconis: 16 h. 32 m. 23 s., N. 66° 57·8′. Discovered by Geelmuyden in 1876. Max. 6·5 to 8·7; min. 12 to 13. Mean period, 245·6 days. Maxima were observed by Grover on July 28, 1901 (7·2 magnitude), March 25, 1902 (7·2 magnitude), and November 3, 1902 (6·3 magnitude).

S Herculis: 16 h. 47 m. 21 s., N. 15° 6·6′. Discovered at Bonn in 1856. Max. 5·9 to 7·5; min. 11·5 to 13. Mean period, 309·2 days, but with large irregularities. The star is reddish, and the spectrum of the third type. It lies closely south-west of the star 49 Herculis (6½ magnitude). A maximum (7·1 magnitude) was observed by Grover on May 16, 1901 (interval since last maximum, 290 days), and at Harvard (7 magnitude) about June 6, 1901. At some minima Grover has seen it surrounded by 'a bluish nebulosity.'

RR Scorpii: 16 h. 50 m. 15 s., S. 30° 25·3′. Discovered by Thome in 1892. Max. 6·2 to 7; min. 9·3 to 10. Mean period, 282·7 days.

X Ophiuchi: 18 h. 33 m. 35 s., N. 8° 44·4′. Discovered by Espin in 1886. Max. 6·8 to 7; min. 9. Period, 335 days.

R Aquilæ: 19 h. 1 m. 33 s., N. 8° 4·8′. About 3° south of 18 Aquilæ. Discovered at Bonn in 1856. Max. 5·9 to 7·4; min. 10·9 to 11·5. Mean period, 350·6 days. The increase of light from ninth magnitude to seventh magnitude is very rapid. The star is reddish, and its spectrum of the third type. A maximum was observed by H. M. Parkhurst on September 22, 1901 (6·12 magnitude), and another by Dr. Kelly about July 28, 1902.

R Cygni: 19 h. 34 m. 8 s., N. 49° 58·5′. Discovered by Pogson in 1852. It lies about 22 seconds of time to the east of the 4·5 magnitude star θ Cygni, and can thus be easily found with an opera-glass when at its maximum light. Max. 5·9 to 8; min. below 14. Mean period, 425·7 days. The star is reddish, and the spectrum of the third type. Bright lines were seen in the spectrum in 1888. The existence of these were con-

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[1] *Astronomische Nachrichten*, No. 3,835.

firmed by Maunder at Greenwich, and one of them was found to coincide with the F line of hydrogen.[1] Peek has seen a bluish nebulosity at minimum. A maximum (6·62 magnitude) was observed at Harvard on June 11, 1901, and another (8 magnitude) by Grover on September 3, 1902.

χ Cygni: 19 h. 46 m. 44 s., N. 32° 9·7′. Discovered by Kirch in 1686. Max. 4 to 6·5; min. 13·5. Mean period, 406 days, but with some irregularities. A most remarkable and interesting variable. Distinctly visible to the naked eye at a bright maximum. The light variation is enormous, amounting to nearly, if not quite, ten magnitudes! This implies that the light at a bright maximum is nearly 10,000 times the light at minimum! A maximum (4·2 magnitude) was observed by Grover on August 14, 1901, and another on September 4, 1902 (4·3 magnitude)[2]—interval 386 days. The star is red, and shows a magnificent spectrum of the third type, in which bright lines (D_3 very plain) were seen by Espin in May, 1899. It is the true χ Cygni of Bayer, and is often confused with Flamsteed 17 Cygni, to which Flamsteed affixed the letter χ by mistake, the variable having been faint at the date of Flamsteed's observation. It is sometimes called χ^2 Cygni, but this is an error.

T Cephei: 21 h. 8 m. 13 s., N. 68° 5·0′. A little south-west of β Cephei. Discovered by Ceraski in 1878. Max. 5·2 to 6·8; min. 8·6 to 10·7. Mean period, 387 days. The increase of light is slower than the decrease. The star is reddish, and has a fine spectrum of the third type, with dark bands of considerable intensity. A maximum (5·3 magnitude) was observed by Grover on February 6, 1901, and another February 1, 1902 (interval 360 days). The star is D.M. 67°, 1291.

W Cygni: 21 h. 32 m. 14 s., N. 44° 55·6′. Closely south of ρ Cygni. Discovered by Gore in 1885. Max. 5 to 6·3; min. 6·7 to 7. Mean period, 131·5 days. Sawyer finds that

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[1] *Monthly Notices*, R.A.S., March, 1889. According to Mrs. Fleming, bright hydrogen lines are characteristic of the long-period variables (*Astrophysical Journal*, November, 1898, p. 233).

[2] A maximum was observed by Dr. Kelly on September 7, 1902 (4·1 magnitude).

'the light curve exhibits a rather rapid and uniform increase, with a somewhat less rapid and irregular decrease.' Its colour is reddish, and the spectrum a remarkable one of the third type, which Dunér describes as 'd'un beauté extraordinaire,' with very wide and very black bands. Max. about August 30, 1901 (5·5 m.).

R Pegasi: 23 h. 1 m. 38 s., N. 10° 0·2′. Discovered by Hind in 1848. Max. 6·9 to 7·9; min. below 13. Mean period, about 380 days, but with considerable irregularities. A maximum was observed by Dr. Kelly on August 10, 1902 (7·45 magnitude).

R Aquarii: 23 h. 38 m. 39 s., S. 15° 50·3′. About 1° south-west of ω^2 Aquarii Discovered by Harding in 1811. Max. 5·8 to 8·5; min. about 11. Mean period, 387 days, but with some irregularities. The increase from tenth magnitude is rapid. The colour is reddish, and the spectrum of the third type. A maximum (7·16 magnitude) was observed at Harvard on December 9, 1900, and another (6·54 magnitude) on December 27, 1901.

V Cephei: 23 h. 51 m. 44 s.; N. 82° 38·1′. Discovered by Chandler in 1882. Max. 6·2 to 6·4; min. 6·8 to 7·1. Mean period, 360 days.

R Cassiopeiæ: 23 h. 53 m. 19 s., N. 50° 50′. Discovered by Pogson in 1853. Max. 4·8 to 7·6; min. 9·7 to 12. Mean period, 429·5 days, with some irregularities. The colour is reddish. Peek called it 'fiery red,' and says: 'There is a slight hazy look round the star, as if seen through an atmosphere.' A maximum (7·6 magnitude) was observed by Grover on December 2, 1902 (interval since last maximum, 414 days). Spectrum of the third type. In September, 1899, Espin found the lines D_3 and $H\gamma$ bright.

In addition to the above, there are many other known variables of long period, but they are mostly faint, even at maximum, and not well within the reach of amateurs with small telescopes.

It will be noticed in the preceding list that in some cases the observed interval between two maxima does not agree well with the mean period found by previous observations. In these cases the observer should add the mean period (or multiples of the period) given to the observed date of maximum, and then watch the star at the next maximum to see whether it is before or after its time. In this way much useful work may be done by amateur observers—work which does not come within the province of the professional astronomer.

Irregular Variable Stars.—There are a number of stars which are certainly variable in light, but which seem to have no regular period. In most of these the amount of variation is small, and sometimes not easily detected. There are, however, some interesting objects in this class.

The following are among the most interesting of the irregular variables:

α Cassiopeiæ: R.A., 0 h. 34 m. 50 s., N. 55° 59·3′. Discovered by Birt in 1831; confirmed by Sir John Herschel and others. Variation from 2·2 to 2·8 magnitude. Chandler says: 'Variation only occasionally evident.' Colour reddish. Spectrum of the second type (K, Pickering).

ρ Persei: 2 h. 58 m. 46 s., N. 38° 27·2′. Discovered by Schmidt in 1854 while using it as a companion star for Algol. Max. 3·4; min. 4·2. The colour is yellowish, and Dunér calls the spectrum 'superbe.' Third type.

ε Aurigæ: 4 h. 54 m. 47 s., N. 43° 40·5′. Suspected by Fritsch in 1821; confirmed by Schmidt 1843, and independently by Heis in 1847. Max. 3; min. 4·5. Colour nearly white. Spectrum of the second type (F, Pickering).

α Orionis (Betelgeuse): 5 h. 49 m. 45 s., N. 7° 23·3′. Discovered by Sir John Herschel in 1840. It varies from about 0·2 to 1 magnitude, with no regular period. The star is very reddish, and the spectrum a fine one of the third type.[1] I found the star unusually bright on October 16, 17, and 26, 1902. It was then brighter than Procyon, and equal to Capella.

η Argus: 10 h. 41 m. 11 s., S. 59° 9·5′. Discovered by Burchell in 1827. This famous variable star is one of the most remarkable objects in the heavens, varying as it has done through all grades of brightness, from that of Sirius to below the seventh magnitude! It was observed by Halley in 1677,

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[1] Al-Sufi (tenth century) rated it 1-2 magnitude, and called Aldebaran first magnitude.

and rated fourth magnitude. Lacaille estimated it second magnitude in 1751. Burchell saw it fourth magnitude from 1811 to 1815. It seems to have been of the second magnitude from 1822 to 1826, but on February 1, 1827, Burchell found it first magnitude and equal to α Crucis, and in February, 1828, between the first and second magnitude. From 1829 to 1833 Johnson and Taylor rated it second magnitude, and it was about this magnitude, or rather brighter, when Sir John Herschel commenced his observations at the Cape of Good Hope in 1834; and so it remained till December 16, 1837, when Herschel was surprised to find its light 'nearly tripled.' It was then brighter than Procyon, and 'far superior to Aldebaran. It exceeded α Orionis, and the only star (Sirius and Canopus excepted) which could at all be compared with it was Rigel.' Its light continued to increase, and on December 28 it was nearly equal to α Centauri. The maximum seems to have been reached about January 2, 1838, when Sir John Herschel found it exactly equal to α Centauri. After this its light began to decrease, but it was not 'until April 14, 1838, that it had so far faded as to bear comparison with Aldebaran, though still somewhat brighter than that star.'[1] In 1843 it again increased in brightness, and in April of that year it was observed by Maclear to be brighter than Canopus and nearly equal to Sirius! It then faded a little, but seems to have remained at nearly the brightness of Canopus till February, 1850, since which time it has gradually decreased. It was still of the first magnitude in 1856, according to Abbott, but was rated 2·3 by Powell in 1858; third magnitude in 1860 by Tebbutt; 4·2 in 1861 by Abbott; fifth magnitude in 1863 by Ellery; and sixth magnitude in 1867 by Tebbutt. In 1874 it was estimated 6·8 at Cordoba, and only 7·4 in November, 1878. In 1878 Markwick estimated it 7·51. Tebbutt's observations from 1877 to 1886 show that it did not rise above the seventh magnitude in those years. In March, 1886, it was rated 7·6 by Finlay at the Cape of Good Hope. In May, 1888, Tebbutt thought that it 'had increased fully half a magnitude' since April, 1887, and might be rated as seventh magnitude. In 1896 Mr. R. T. A. Innes

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[1] 'Cape Observations,' p. 34.

found its mean magnitude 7·58 ; in 1900, 7·68 ; in 1901, 7·78 ; and in January and February, 1902, 7·72. Schönfeld thought that a regular period is very improbable, although a period of 46 years was suggested by Wolf, and about 67 years by Loomis. The star is situated in the densest portion of one of the most remarkable nebulæ in the heavens. It is reddish, and the spectrum very similar to that of the temporary stars. It may perhaps be considered as a sort of connecting link between long-period variables and temporary stars.

R Coronæ : 15 h. 44 m. 47 s., N. 28° 27·8′. Between α and ι Coronæ. Discovered by Pigott in 1795. Max. 5·8 ; min. 13. A remarkable but very irregular variable, sometimes remaining for a whole year at a maximum, with little or no perceptible change. In the years 1862 and 1863 it remained, according to Schmidt, of about the sixth magnitude for a year and a half ! The present writer found it visible to the naked eye in the Punjab from April 14, 1877, to August 1, 1877. At times, however, it descends to a minimum with great rapidity. A bright minimum of 7·4 magnitude was observed by Sawyer on October 13, 1885. The colour is nearly white, and the spectrum of the third type, according to Pickering. Bright lines have been seen by Espin.

30 (g) Herculis ; 16 h. 25 m. 21 s., N. 42° 6 1′. Discovered by Baxendell in 1857. Max. 4·7 to 5·5 ; min. 5·4 to 6. The spectrum is a fine example of the third type.

α Herculis : 17 h. 10 m. 5 s., N. 14° 30·2′. Discovered by Sir William Herschel in 1795. Max. 3·1 ; min. 3·9. Variation often scarcely perceptible. Various periods have been assigned ; Chander says : 'Two or three months, with wide fluctuations from the mean.' Colour reddish, with a fine spectrum of the third type.

V Aquilæ : 18 h. 59 m. 4 s., S. 5° 50′. Detected by several observers : Knott, 1871 ; Schmidt, 1872 ; Safarik, 1884 ; Sawyer, 1892. Max. 6·5 ; min. 8. It is a very red star, and is No. 483 of Birmingham's Catalogue (584 Espin) and lies a little south of λ Aquilæ.

RV Sagittarii : 19 h. 10 m. 1 s., S. 33° 42′. Discovered by Markwick. Variation from 6·5 to below 11 magnitude. According to Roberts, 'there is apparently no regular period, although there is evidence of a rough cycle of eighteen months.' Professor Pickering found the spectrum peculiar and with bright lines.[1]

μ Cephei: 21 h. 40 m. 27 s., N. 58° 19·3′. Discovered by Hind in 1848. Confirmed by Argelander. This is Sir W. Herschel's 'garnet star,' perhaps the reddest star visible to the naked eye in the Northern Hemisphere. Numerous observations by the present writer in the years 1883 to 1899 show that the star is certainly variable from about 3·7 to 4·8 magnitude, but with apparently no regular period. Bright phases were observed on February 13 and May 11, 1885, when μ was very little inferior to ζ Cephei. The spectrum is a very fine one of the third type, 'the separating spaces being sharp, dark, and very broad.'

β Pegasi: 22 h. 58 m. 55 s., N. 27° 32·4′. Discovered by Schmidt in 1847. Variation from 2·2 to 2·7 magnitude.

Short-Period Variables.—This is a most remarkable and interesting class of variable stars. Most of those hitherto discovered may be followed with the naked eye or a binocular field-glass through all their changes of brightness. The periods range from a few hours to several days. In a few cases the periods are longer, and extend to twenty to fifty days. The increase of light is usually more rapid than the decrease, but there are some exceptions to this rule.

The following list includes the most interesting of the short-period variables now known. They are given in order of right ascension, and the positions are for 1900:

ζ Geminorum: 6 h. 58 m. 11 s., N. 20° 43′. Discovered by Schmidt in 1847. Variation from 3·7 to 4·5 magnitude. Period 10·15382 days = 10 d. 3 h. 41·5 s. It was found to be a spectroscopic binary by Campbell and Wright, but—like η Aquilæ and δ Cephei—the variation does not seem to be due to an eclipse. Spectrum of second type (G).

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[1] *Astrophysical Journal*, August, 1896, p. 140.

V Carinæ: 8 h. 26 m. 41 s., S. 59° 47·3′. Discovered by Roberts in 1892. Max. 7·4; min. 8·1. Period, 6·6951 days.

T Velorum: 8 h. 34 m. 26 s., S. 47° 0·7′. Discovered by Roberts in 1892. Max. 7·65; min. 8·5. Period, 4·6392 days.

V Velorum: 9 h. 19 m. 15 s., S. 55° 32·0′. Discovered by Roberts in 1892. Variation from 7·5 to 8·2 magnitude. Period, 4·3709 days. Roberts says: 'Light variation very regular. Ascent to a maximum rapid.'[1]

S Muscæ: 12 h. 7 m. 24 s., S. 69° 35·7′. Discovered by Roberts in 1891. Varies from 6·4 to 7·3 magnitude. Period, 9·657 days. Light curve irregular.

T Crucis: 12 h. 15 m. 54 s., S. 61° 43·6′. Discovered by Roberts, 1895. Variation from 6·85 to 7·6 magnitude. Period, 6·7322 days. Light variation regular.

R Crucis: 12 h. 18 m. 8 s., S. 61° 4·5′. Discovered by Roberts in 1891. Variation from 6·8 to 7·9 magnitude. Period, 5·82485 days. 'Variation very regular. Maxima and minima very distinctly marked.'[1]

R Muscæ: 12 h. 35 m. 59 s., S. 68° 51·5′. Discovered by Gould in 1871. Variation from 6·5 to 7·6 magnitude. Period, 0·882495 day=20 h. 10 m. 47·5 s. 'Variation very interesting.' 'There is no evidence of secular change in the period of the star' (Roberts). Gould remarked that 'its average brightness is so near the limit of ordinary visibility in a clear sky at Cordoba that the small regular fluctuations of its light place it every few hours alternately within or beyond that limit.'

S Crucis: 12 h. 48 m. 27 s., S. 57° 53·3′. Discovered by Roberts, 1891. Varies from 6·5 to 7·6 magnitude. Period, 4·68989 days. Roberts says: 'An almost typical example of short-period variation. Descent to a minimum as well as ascent to a maximum continuous.'

V Centauri: 14 h. 25 m. 23 s., S. 56° 26·6′. Discovered by Roberts in 1894. Max. 6·4 to 6·6; min. 7·8. Period, 5·49394 days. 'At maximum the rate of variation is rapid' (Roberts).

T Trianguli Australis: 15 h. 0 m. 24 s., S. 68° 20·1′. Discovered at Cordoba; confirmed by Roberts. Variation from 6·9 to 7·4 magnitude. Period, 0·98 day, or 23 h. 31 m.

R Trianguli Australis: 15 h. 10 m. 49 s., S. 66° 7·7′. Dis-

[1] *Astronomical Journal*, February 16, 1901.

covered at Cordoba, 1871. Varies from 6·7 to 7·4 magnitude. Period, 3·3891 days, or 3 d. 9 h. 20·3 s. Light curve regular.

S Trianguli Australis: 15 h. 52 m. 12 s., S. 63° 29·5′. Discovered at Cordoba. Variation from 6·4 to 7·4 magnitude. Period, 6·3231 days.

U Trianguli Australis: 15 h. 58 m. 25 s., S. 62° 38·3′. Discovered by Roberts in 1893. Variation from 7·75 to 8·4 magnitude. Period, 2·5683 days. 'Almost stationary at its maximum for about twelve hours' (Roberts).

S Normæ: 16 h. 10 m. 35 s., S. 57° 39·2′. Discovered by Roberts. Max. 6·6; min. 7·4 to 7·55. Period, 9·7525 days. According to Roberts, it 'departs considerably from the ordinary type of short-period variation, the ascending period being almost of the same duration as the descending period.'

X (3) Sagittarii: 17 h. 41 m. 16 s., S. 27° 47·6′. Discovered by Schmidt in 1866. Varies from 4 to 6 magnitude. Period, 7·01185 days, but this requires a small correction. The spectrum is of the second type (K, Pickering).

Y Ophiuchi: 17 h. 47 m. 17 s., S. 6° 7·1′. Discovered by Sawyer in 1888. Variation from 6·2 to 8 magnitude. Period, 17·1207 days.

W (γ^1) Sagittarii: 17 h. 58 m. 38 s., S. 29° 35·1′. Discovered by Schmidt in 1866. Varies from 4·8 to 5·8 magnitude. Period, 7·59460 days.

Y Sagittarii: 18 h. 15 m. 30 s., S. 18° 54·3′. Discovered by Sawyer in 1886. Variation 5·8 to 6·6 magnitude. Period, 5·7732 days. The colour is white, and the spectrum of the second type (G, Pickering).

59 (*d*) Serpentis: 18 h. 22 m. 6 s., N. 0° 8·2′. Discovered by Müller and Kempf in 1891. Varies from 5 to 5·7 magnitude. Period, 8·72 days. The spectrum is of the first or Sirian type.

U Sagittarii: 18 h. 26 m. 0 s., S. 19° 11·7′. Discovered by Schmidt in 1866. Variable from 7 to 8·3 magnitude. Period, 6·7446 days.

β Lyræ: 18 h. 46 m. 23 s., N. 33° 14·8′. Discovered by Goodricke in 1784. Variation from 3·4 to 4·5 magnitude. Mean period, 12 d. 21 h. 46 m. 58·3 s. (Reed). A remarkable and interesting variable. There are two maxima of 3·4 magnitude, and two minima, one 3·9 and one (the chief minimum) 4·5 magnitude. Situated as it is near a good comparison star, γ Lyræ, the fluctuations in the light of β Lyræ are very evident and interesting, and can be well observed with the naked eye. In recent years the star has been found to be a spectroscopic binary, a fact which seems to be in some way connected with the star's variation (see Spectroscopic Binaries in last chapter). The spectrum is of the second type (G, Pickering).

κ Pavonis: 18 h. 46 m. 38 s., S. 61° 21.5′. Discovered by Thome in 1872. Variation from 3·8 to 5·2 magnitude. Period, 9·0908 days. A very interesting variable star, as all the light changes can be observed with the naked eye. 'Light curve regular.' Period seems to be constant. There is an approximate equality between the ascending and descending rates of variation.

U Vulpeculæ: 19 h. 32 m. 15 s., N. 20° 6·6′. Varies from 7 to 7·68 magnitude. Period, 7·97997 days.

U Aquarii: 19 h. 38 m. 58 s., S. 7° 15′. Discovered by Sawyer in 1886. Varies from 6·4 to 7·1 magnitude. Period, 7·0240 days. The star is white.

η Aquilæ: 19 h. 47 m. 23 s., N. 0° 45′. Discovered by Pigott in 1784. Variation from 3·5 to 4·7 magnitude. Mean period, 7 d. 4 h. 14 m., with oscillations of a few hours in the time of maxima and minima, according to Dr. W. J. S. Lockyer. From spectroscopic observations Belopolsky finds evidence of orbital motion in a period of 7 days 4 hours, but he thinks that the variation of light cannot be produced by an eclipse (as in the case of Algol), as the times of observed minima do not agree with the time of an eclipse in the computed orbit. The colour of the star is yellow, and the spectrum of the second type (G).

S (10) Sagittæ: 19 h. 51 m. 29 s., N. 16° 22·2′. Discovered by Gore in 1885. Variation from 5·6 to 6·4 magnitude. Period, 8·38320 days=8 d. 9 h. 11 m. 48 s. The minimum occurs 3·40 days before the maximum. Owing to its proximity to a good comparison star—11 Sagittæ—the fluctuations of light, although comparatively small, are very evident and interesting when observed with an opera-glass or binocular field-glass, with which instrument the variability was discovered. At the maximum it is slightly brighter than 11 Sagittæ, and at the minimum considerably fainter. Espin remarks that the star is 'about four days visible to the naked eye, and four days invisible.' The colour is white.

X Cygni: 20 h. 39 m. 29 s., N. 35° 13·6′. A little south-west of λ Cygni. Discovered by Chandler in 1886. Max. 6·4; min. 7·2 to 7·7. Period, 16·3855 days. An interesting variable. 'The increase of light occupies four days, the decrease ten days, with a halt in the latter about midway of its course.' There are bright and faint minima, but regularly alternating. The colour is white. Can be well observed with an opera-glass.

T Vulpeculæ: 20 h. 47 m. 13 s., N. 27° 52·5′. Closely north-west of 32 Vulpeculæ. Discovered by Sawyer in 1885. Variable from 5·5 to 6·5 magnitude. Period, 4·4360 days, or 4 d. 10 h. 27 m. 50 s. The minimum occurs about 1·4 days before the maximum. A very interesting variable, and can be well observed with an opera-glass. The colour is white, and the spectrum of the second type (F, Pickering).

δ Cephei: 22 h. 25 m. 27 s., N. 57° 54·2′. Discovered by Goodricke in 1784. Variation from 3·7 to 4·9 magnitude. Period, 5 d. 8 h. 47 m. 39·3 s., with some irregularities. A very interesting variable. All the light fluctuations can be observed with the naked eye. The colour is yellowish, and the spectrum of the second type (G). It is a spectroscopic binary, but, like η Aquilæ, the light changes are not well accounted for by the orbital motion of two components.

The following have longer periods, and seem to form a connecting link between the short-period and long-period variables:

T Monocerotis: 6 h. 19 m. 49 s., N. 7° 8·4′. About 2½° west of 13 Monocerotis. Max. 5·8 to 6·4; min. 7·4 to 8·2. Period, 27·0122 days (Yendell). It can be followed through all its changes with a binocular field-glass. The spectrum is of the second type (G, Pickering). Maxima were observed by Yendell, 1902, January 31, March 3, and March 29.

U Monocerotis: 7 h. 26 m. 1 s., S. 9° 34′. Discovered by Gould, 1873. Max. 5·9 to 7·3; min. 6·6 to 8. Period, 46·1 days, but with some irregularities. The spectrum is of the second type (K, Pickering). Can be well observed with an opera-glass.

– Cygni: 21 h. 38 m. 46 s., N. 43° 7·6′. Discovered by Miss

Wells at Harvard. Variation from 7·2 to 11·2 magnitude (photographic magnitudes). Period, about 40 days. The variation is unusually large for so short a period.

Most of the short-period variables lie in or near the Milky Way. The only well-marked exception to this rule seems to be W Virginis, a faint star with a period of about 17·27 days.[1]

Algol Variables. — The famous variable star Algol (β Persei) is the type of this interesting class of variables. The character of the variation is a peculiar one, and is quite different from other variables. All the light fluctuations take place in the course of a few hours, while for the remainder, and much the longer portion, of the period the light remains constant at a maximum. The number of these variables known at present is comparatively small, but since the discovery of spectroscopic binaries it has become probable that they may be much more numerous than is generally supposed. Owing to the character of the variation, their discovery is a matter of no small difficulty. A minimum of a star of this class may be observed by chance, but, from ignorance of its period, we cannot tell when to expect another minimum, and consequently a long time may elapse before the suspicion of variability can be confirmed. It seems certain now that the variation of light in stars of this class is due to an eclipse by a dark or bright comparison.

The following list includes, I think, all the variables of this class hitherto discovered.[2] Some of them are faint, and can only be observed with a good telescope. They are given in order of R.A.

U Cephei: 0 h. 53 m. 23 s., N. 81° 20·2′. Discovered by Ceraski in 1880. Max. 7·1; min. 9·2 to 9·5. Period, 2 d. 11 h. 49 m. 38 s. The light fluctuations occupy about ten hours, or about one-sixth of the period. The light is stationary for nearly two hours at the minimum. Decrease of light more

[1] See Appendix, Note M. [2] December, 1902.

rapid than the increase. The colour is white, but turns 'ruddy' near the minimum. The spectrum is of the first or Sirian type, a feature usual in variables of this class.

– Persei = D M + 41°, 504 : 2 h. 33 m. 23 s., N. 41° 48·7′. Discovered by Stanley Williams, 1902. Varies from 9·4 to nearly 12 magnitude. Period, 3 d. 1 h. 21 m. 32·23 s.

Algol (β Persei): 3 h. 1 m. 40 s., N. 40° 34·2′. Discovered by Montanari in 1669, and independently in 1782 by Goodricke, who determined its period. Max. 2·3; min. 3·5. Mean period at present, 2 d. 20 h. 48 m. 55·6 s., but subject to a secular variation of a few seconds. The light changes occupy a little over nine hours. Schmidt found that the brightness of Algol is equal to that of δ Persei about forty-seven minutes before and after minimum; to that of ε Persei about sixty-two minutes before and after the same; and to that of β Trianguli ninety-five minutes before and after minimum. Vogel found, from observations with the spectroscope in 1888 to 1889, that the variation of light is caused by a dark eclipsing satellite—a theory originally suggested by Goodricke. Vogel's observations show that the distance between the components is about 3,250,000 miles from centre to centre, and their diameters about 1,060,000 and 830,000 miles respectively. From this it follows that the combined mass is about two-thirds that of the sun. The star is at present white, but is recorded as red by the Persian astronomer Al-Sufi in the middle of the tenth century—a remarkable instance of change of colour in a star. The spectrum is of the first or Sirian type (A, Pickering).

λ Tauri: 3 h. 55 m. 8 s., N. 12° 12·5′. Discovered by Baxendell in 1848. Varies from 3·4 to 4·2 magnitude. Mean period, 3 d. 22 h. 52·2 m., but with inequalities sometimes amounting to 3 hours. The spectrum is of the first type (B 3 A, Pickering).

R Canis Majoris: 7 h. 14 m. 56 s., S. 16° 12·4′. Discovered by Sawyer in 1887. It varies from 5·9 to 6·7 magnitude. Period, 1 d. 3 h. 15 m. 46 s. The light fluctuations occupy about five hours. The spectrum is of the second type (F, Pickering).

RR Puppis: 7 h. 43 m. 31 s., S. 41° 7·6′. Discovered by R. T. A. Innes in 1895. Variation from 10 to 11 magnitude. Period, 6 d. 10 h. 19 m. 25 s. Variation regular. The light fluctuations occupy about fourteen hours, and at minimum the light is stationary for about eight and a half hours. Roberts says: 'The light changes are accounted for by the revolution in the plane of sight of two stars, one three and a half times larger than the other, the smaller star being, however, one and a half times brighter than its larger companion. On this supposition, a secondary minimum would be practically inappreciable.'[1] He finds that the density of the component stars cannot be greater than 0·16 (sun's density = 1).[2]

V Puppis = Lacaille 3105: 7 h. 55 m. 22 s., S. 48° 58·4′. Discovered by Williams in 1886. Max. 4·14; min. 4·66 to 4·78. Period, 1 d. 10 h. 54 m. 26·7 s. (Roberts). 'Light curve of the same type as U Pegasi. Variation continuous and symmetrical on either side of minima.'[1] There is no stationary period at minimum. The spectroscope shows the star to be a close binary. Professor Pickering says: 'The period 1·454 days satisfies the observations of the changes, and of the varying separation of the lines in the spectrum.' Spectrum of brighter component appears to be class B 1 A, that of the fainter B 3 A. 'The separation is very large, and micrometer measures give the relative velocity of the two components as 610 kilometres'[3] (378 miles!) a second. This gives a mass of over seventy times the mass of the sun! According to Roberts, the density cannot be greater than 0·02 of the sun's density, and he thinks that 'the two component stars revolve round one another *in actual contact*.' (The italics are Roberts'.)

X Carinæ: 8 h. 29 m. 7 s., S. 58° 53·2′. Discovered by Roberts in 1892. Max. 7·9; min. 8·60 to 8·68. Period, 12 h. 59 m. 29·9 s. 'Light variation very regular. There is no stationary phase at minimum' (Roberts, who thinks the period may possibly be double that given above).

S Cancri: 8 h. 38 m. 14 s., N. 19° 23·6′. Between γ and δ Cancri. Discovered by Hind in 1848. Variation, 8·2 to 9·8 magnitude. Period, 9 d. 11 h. 37 m. 45 s. The light fluctuations occupy twenty-one and a half hours. Argelander remarked that after minimum the light begins to increase very rapidly, and he was inclined to think that the descent from the maxima is even still more rapid. It was once observed very faint at minimum.

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[1] *Astrophysical Journal*, Nos. 491, 492 (1901, February 16), p. 88. [2] *Ibid.*, April, 1901.

[3] *Annals of Harvard College*, vol. xxviii., part ii., p. 177.

S Antliæ: 9 h. 27 m. 56 s., S. 28° 11·2′. Discovered by Paul in 1888. Varies from 6·7 to 7·3 magnitude. Period, 7 h. 46 m. 48 s. The light fluctuations occupy about three and a half hours. Pickering finds that the light curve does not resemble those of β Lyræ and U Pegasi. The period is one of the shortest known, the star going through all its fluctuations of light three times over within twenty-four hours!

S Velorum: 9 h. 29 m. 17 s., S. 44° 45·9′. Discovered by Woods in 1894. Variation from 7·8 to 9·3 magnitude. Period, 5 d. 22 h. 24 m. 21·1 s. Variation very regular. The light fluctuations occupy about fifteen hours, and the light is stationary at minimum for 6 h. 18 m. Roberts says: 'The passing into and from the stationary phase is abrupt; the form of the light curve at these two points being practically a right angle. . . . The explanation that naturally suggests itself is that in stars of this type of variation we have two bodies, one bright and small, the other dark and large, revolving round one another, the darker body eclipsing the brighter each revolution.'

– Velorum: 10 h. 16 m. 44 s., S. 41° 43·8′. Discovered by Roberts in 1901. Varies from 10 to 10·9 magnitude. Period, 1 d. 20 h. 30 m. 2 s. The light changes occupy 3 h. 20 m. No stationary period at minimum. Ascending and descending phases equal.

RR Centauri: 14 h. 9 m. 55 s., S. 57° 23·3′. Varies from 7·4 to 7·85 magnitude. Period, 7 h. 16 m. 5·5 s. It seems to be a sort of connecting link between the short-period variables and those of the Algol type. 'Variation within narrow limits, usually half a magnitude, very rapid and very regular' (Roberts).

δ Libræ: 14 h. 55 m. 38 s., S. 8° 7·3′. Discovered by Schmidt in 1859. Variation from 5 to 6·2 magnitude. Period, 2 d. 7 h. 51 m. 22·8 s. Light fluctuations occupy twelve hours. The spectrum is of the first or Sirian type.

U Coronæ: 15 h. 14 m. 7 s., N. 32° 0·8′. Discovered by Winnecke in 1869. Varies from 7·5 to 8 9 magnitude. Period, 3 d. 10 h. 51 m. 12·4 s., with some irregularities. The light fluctuations occupy nearly ten hours.

R Aræ: 16 h. 31 m. 26 s., S. 56° 47·6′. Discovered by Roberts, 1891. Variation from 6·8 to 7·9 magnitude. Period, 4 d. 10 h. 12 m. 7·9 s. Light fluctuations occupy 9 h. 12 m. No stationary phase at minimum.

U Ophiuchi: 17 h. 11 m. 27 s., N. 1° 19·3′. A little north of 41 Ophiuchi. Discovered by Gould, 1871, and Sawyer, 1881. Variation from 6 to 6·7 magnitude. Period, 20 h. 7 m. 42·56 s., with some irregularities. Light fluctuations occupy five hours. Observations by Chandler and Sawyer show a curious 'standstill' in the light increase for some fifteen minutes after the minimum. Colour white, and spectrum of the first type (B, Pickering).

Z Herculis: 17 h. 53 m. 26 s., N. 15° 8·8′. Variation discovered by Müller and Kempf. Found by Chandler to be of the Algol type. Max. 6·89; min. 7·35 to 8·05. Period, 3 d. 23 h. 49 m. A secondary minimum occurs 'about three hours earlier than the midway point between the principal minima' (Chandler). The relative brightness at maximum, secondary minimum, and principal minimum are in the proportion of 3 : 2 : 1. From a mathematical investigation of the orbit described by the two components Dunér arrives at the following conclusions: 'Z Herculis consists of two stars of equal size, one of which is twice as bright as the other. The stars revolve around their centre of gravity in an elliptical orbit, whose semi-axis major is six times the diameter of the stars. The plane of the orbit passes through the sun, the eccentricity is 0·2475, and the line of apsides is inclined at an angle of 4° to the line of sight. The stars revolve in this orbit in 3 days 23 hours 48 minutes 30 seconds,' and he adds: 'Hence Z Herculis stands in an isolated position among stars of the Algol type, or, rather, forms a hitherto missing link between stars of the pure Algol type and Y Cygni.'[1] (See Appendix, Note I.)

S Sagittarii: 18 h. 10 m. 59 s., S. 34° 8·5′. Discovered by Gould in 1874. Max. 6·6; min. 6·9 to 7·6. Period, 2 d. 9 h. 58 m. 36·7 s. The duration of the principal minimum is twelve and a half hours, and that of the secondary eight hours.

– Serpentis DM + 12°, 3557: 18 h. 26 m. 1 s., N. 12° 32·6′. Discovered by Sawyer. Variation from 7 to 7·5 magnitude. Period, 0 d. 21 h. 21 m.

– Scuti: 18 h. 48 m. 24 s., S. 12° 48·6′. Discovered by Ceraski in 1901. Variation from 9 to 9·6 magnitude. Period, 22·9 hours.

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[1] *Astrophysical Journal*, April, 1895.

— Lyræ: 19 h. 12 m. 23 s., N. 32° 15·5′. Discovered by Stanley Williams, 1902. Variation from 11 to 12·8 magnitude. Period, 3 d. 14 h. 22 m. 23½ s. Light fluctuations eight hours.

— Sagittæ=DM+19°, 3975: 19 h. 14 m. 26 s., N. 19° 25·4′. Discovered by Schwab, 1901. Max. 6·5; min. nearly 9. Period, 3·38 days=3 d. 9 h. 7 m. Variation unusually large for an Algol star.

— Cygni: 19 h. 42 m. 7 s., N. 32° 28′. Discovered by Madame Ceraski. Variation about 11 to 13 magnitude. Period, 6 d. 0 h. 8·8 m.

— Cygni: 20 h. 4·3 m., N. 46° 1′. Discovered by Madame Ceraski. Varies from 8·6 to below 11 magnitude. Period, 4 d. 13 h. 45 m. 2 s. The variation amounts to about three magnitudes, and therefore exceeds that of any other known Algol variable. Light fluctuations occupy about thirteen hours. Spectrum first type.

— Cygni: 20 h. 19 m. 39 s., N. 42° 55′. Discovered by Stanley Williams, 1901. Varies from 10 to 12 magnitude. Period, 3 d. 10 h. 49 m. Decrease of light takes three and a half hours, increase 4 h. 10 m. Light constant at minimum for fifty minutes.

W Delphini: 20 h. 33 m. 7 s., N. 17° 56′. Discovered by Miss Wells at Harvard Observatory (U.S.A.), 1895. Max. 9·5; min. below 12. Period, 4 d. 19 h. 21·2 m. (Pickering).

Y Cygni: 20 h. 48 m. 4 s., N. 34° 17′. Discovered by Chandler, 1886. Variation from 7·1 to 7·9 magnitude, but variable at minimum. Period for even minima, 1 d. 11 h. 57 m. 27·6 s., and for odd minima 1 d. 11 h. 57 m. 15·2 s. (Dunér). The light fluctuations occupy about eight hours. An investigation of the elliptic elements of this variable by Dr. Dunér leads him to the following result: 'The variable star Y Cygni consists of two stars of equal size and equal brightness, which move about their common centre of gravity in an elliptic orbit, whose major axis is eight times the radius of the stars. The period of an anomalistic revolution is 2·996933 days, and the eccentricity is 0·145. A minimum occurred while the stars were at perihelion (?) at 21 h. 26 m. G.M.T. on December 8, 1885. The line of apsides of the orbit, which then coincided with the line of sight, completes one revolution in the plane of the orbit in 41·1 tropical years' (*Astrophysical Journal*, April, 1900).

– Cygni : 21 h. 2·3 m., N. 45° 22·6′. A little north of ξ Cygni. Discovered by Madame Ceraski from photographs (1902). Variable from about 11 to 12 magnitude. Period, probably about 18 days.

– Cygni = DM 43°, 4101 : 21 h. 55·2 m., N. 43° 52′. Not far from the variable SS Cygni. Variation from 8·9 to 11·6 magnitude. Period, about 31·304 days—a very long period for a variable of this class. Duration of minimum about two days.

U Pegasi : 23 h. 52 m. 53 s., N. 15° 23·9′. Discovered by Chandler in 1894. Variation from 9 to 9·7 magnitude. Period, 8 h. 59 m. 41 s. (Pickering). The colour is white.

It has been shown by Dr. Roberts, of South Africa, and independently by Professor Russell, of Princeton (U.S.A.), that the density of the Algol variables is very small, ranging from 0·02 in the case of V Puppis to 0·728 in Z Herculis (water = 1).

Cluster Variables.—A large number of variable stars have recently been found in the globular star clusters. Professor Bailey found 132 in the cluster Messier 3 in Canes Venatici! In the cluster No. 5272 of the New General Catalogue of Nebulæ he found 113. In the cluster Messier 5, 85 have been detected out of 750 stars, and 122 in the great Southern cluster ω Centauri. Variables have also been found in some other clusters, but in the well-known cluster in Herculis, Messier 13, there are very few, if any.

The mean period of forty of the variables is the cluster Messier 5 is 0·526 d., or 12 h. 37·4 m., the longest period being 14 h. 58·6 m., and the shortest 10 h. 48 m. The range of variation is between 0·7 and 1·4 magnitude. The light curves are all very similar, showing a rapid decrease of light, but a much more rapid increase. This has been called the 'cluster type.' There is probably no duration of maximum. In some cases the light at minimum seems to remain constant, or nearly so, for a few hours. In the cluster ω Centauri 'no such uniformity was found,' but it contains many variables of the cluster type.

Professor Bailey divides the whole period of variation of this type as follows:

Duration of maximum phase...	...	0 per cent.
Duration of minimum phase...	...	40 ,,
Duration of decreasing phase	...	50 ,,
Duration of increasing phase	...	10 ,,

The shortest period known is that of No. 91 in ω Centauri, which is 6 h. 11 m., but possibly there may be some with even shorter periods (*Astrophysical Journal*, November, 1899, p. 257).

Suspected Variables.—There are a number of stars which have been suspected of being variable in light, but which have not yet been admitted into the ranks of 'known variables.' They form good objects for observation by amateur astronomers.

The following are some of the most remarkable and interesting cases:

δ Ursæ Majoris: This is the faintest of the well-known seven stars forming the Plough, or 'the Churl's Wain,'[1] and has long been suspected of variation in light. It was rated second magnitude by Tycho Brahé and the Prince of Hesse; Al-Sufi and Argelander made it 3·4; Bradley 3·0, and Heis 4·3. It was measured 3·41 at Harvard. Schönfeld thought that variation was established, with a long period. The spectrum is between the first and second types (A 2 F, Pickering).

α Hydræ: This reddish star, called by the ancient Chinese 'the Red Bird,' and by the Arabians *al-fard* 'the solitary one,' owing to its isolated position in the sky, south of the 'Sickle' in Leo, was suspected to be variable by Sir John Herschel. It was observed to be very bright by Gemmill on February 20, 1882, and again unusually bright on May 9, 1883, when he thought it nearly equal to Pollux. It was rated second magnitude by Ptolemy, Al-Sufi, Argelander, and Heis, but Houzeau estimated it third magnitude in 1875. It was measured 2·02 at Harvard. Its spectrum is between the second and third types (K 2 M, Pickering).

λ Draconis: I have long suspected this star to be variable

[1] Popularly, but erroneously, called 'Charles's Wain.'

in light. My own observations from 1876 to 1891 show decided fluctuations to the extent of nearly one magnitude. It was rated third to fourth magnitude by Ptolemy, Al-Sufi, Argelander, and Heis, but Houzeau made it 4-5 in 1875. The star is of an orange hue, and the spectrum of the third type.

θ Serpentis: This star was rated fourth magnitude by Ptolemy, Al-Sufi, Ulugh Beigh, Lacaille, and Pigott, but third magnitude by Tycho Brahé, Hevelius, Bayer, Flamsteed, Bradley, and De Zach. Piazzi and Smyth made it 4·5, and Montanari called it fifth magnitude. The Cordoba estimates range from 4·1 to 4·6 magnitude, and Gould thought there were strong indications of variability in one of the components (it is a double star). He gives the magnitude as 4·5 and 4·7, but on one occasion at Harvard a difference of 1·4 magnitude was noted between the components.

ϵ Pegasi: This star, which is usually rated about 2·5 magnitude, was found unusually faint by Schmidt in a perfectly clear sky on November 5, 1847. Signs of variation were also noted at Cordoba. Seidel believed it to be variable, and Schwab's observations indicate a period of about 26 days.

83 Ursæ Majoris: This star, which lies near ζ Ursæ Majoris (in the Plough), was seen by Birmingham as bright as δ Ursæ Majoris on August 6, 1868. It was fainter on the following night, and gradually decreased to its usual brightness. It was rated 6-5 magnitude by Argelander, and 5-6 by Heis and Houzeau. It was measured 4·83 magnitude at Harvard. Observations by the present writer seem to indicate some slight variation. It has a spectrum of the third type.

ζ Piscis Australis: This star was rated fifth magnitude by Ptolemy; 5-6 by Al-Sufi; sixth by Ulugh Beigh, Lacaille, and Harding; and 6-5 by Behrmann, Argelander, and Heis. It was estimated sixth magnitude by Houzeau in the year 1875. Gould found it 6·5 to 6·7 from observations at Cordoba. It was measured 6·62 with the photometer at Harvard. From a consideration of the various recorded estimates, C. H. F. Peters concluded that the star is probably variable. The fact of its having been seen at all by Al-Sufi proves beyond reasonable doubt that it must have been brighter in his time than it is at present, and the estimates of Argelander and Heis seem to confirm the variability.

η Crateris: This star was rated 4-3 magnitude by Ptolemy; 5-6 by Al-Sufi; fourth by Ulugh Beigh, Tycho Brahé, and Hevelius; sixth by Argelander and Heis; 5·4 at Cordoba; and only 6-7 by Houzeau. It was measured 5·01 at Harvard. It seems to be certainly variable to a considerable extent; otherwise it seems impossible to explain how a star which was seen only sixth to seventh magnitude by Houzeau, or barely visible to the naked eye, should have been rated fourth magnitude by Tycho Brahé, who was an accurate observer. The period of variation may, however, be very long. The spectrum is of the first or Sirian type.

'The Story of θ Eridani' has been already told in a most interesting paper in *Knowledge* (July, 1893) by Dr. Anderson, the discoverer of Nova Aurigæ and Nova Persei. I fully agree with Dr. Anderson that θ Eridani is identical with the 'Last in the River' of Ptolemy and the *Achernahr* of Al-Sufi, and that, consequently, the star has undoubtedly diminished in brightness from the first magnitude to about the third since the tenth century. It was one of Al-Sufi's thirteen first magnitude stars, and his clear description of its position places its identity beyond all doubt. It was also rated of the first magnitude by Ulugh Beigh, and his position agrees with that of θ Eridani. In recent years it has been suspected of variation in its light. It is a splendid double star—one of the finest in the heavens. The spectrum is between the first and second types (A 2 F).

o Persei: This star and ζ Persei form a conspicuous pair about 8° north of the Pleiades. Al-Sufi, in his 'Description of the Heavens,' written in the tenth century, expressly states that the two stars were exactly equal in brightness (third to fourth magnitude); but o is at present about one magnitude fainter than ζ, and the superior brilliancy of ζ is noticeable at a glance. It seems certain, therefore, that o has diminished in brightness, as the present magnitude of ζ agrees very well with what Al-Sufi made it. Al-Sufi was a most accurate observer. The spectrum of o Persei is of the first type (B 1 A).

γ Geminorum: This star was rated third magnitude by Ptolemy and Al-Sufi, or equal to δ Geminorum; but it is now of the second magnitude, and its superiority in brightness to δ is noticeable at a glance. Spectrum, first type (A).

α Ophiuchi and *β* Canis Majoris were also rated third magnitude by Al-Sufi, but they are now about the second magnitude.

α Sagittarii: 19 h. 16·9 m., S. 40° 48′. This star was rated 2-3 magnitude by Ptolemy, but only 4-5 by Al-Sufi. Lacaille estimated it 3·5. The Harvard measures make it 4·13, thus agreeing well with Al-Sufi's estimate. The spectrum is of the first type (B 8 A).

β Leonis: This star was rated first magnitude by Ptolemy, Al-Sufi, and Tycho Brahé; 1-2 by Flamsteed; but only second magnitude by Lalande, Argelander, Heis, and Houzeau. According to the Harvard photometric measures, it is now below the second magnitude (2·28), and the measures are discordant. Variation was suspected by Sir William Herschel, and the present writer has seen signs of fluctuation in its light. The spectrum is between the first and second types (A 2 F).

There are some telescopic objects which have been suspected of variation. The famous variable star Algol has several faint companions. One of these was discovered in 1787 by Schroter, who strongly suspected it to be variable. A writer in *Nature* (February 20, 1879) stated that he failed to see any trace of the star on several fine nights in the early part of 1874, using a seven-inch refractor; but on September 9 of the same year he saw it very distinctly with the same instrument. It was measured by Talmage at the Leyton Observatory on October 2, 1874, and estimated eleventh to twelfth magnitude, and in 1878 by Burnham, who found three other fainter companions, one not far from Schroter's companion, and forming with it a wide double star. Franks found Schroter's star 'easy enough' with an eleven-and-a-quarter-inch reflector on January 11, 1885, and about two magnitudes brighter than Burnham's companion. Sadler thought it variable from about tenth to fourteenth magnitude in some short period. If variation is confirmed, it would be very interesting, as a variable companion to a known variable star would be a rather unique object.

ζ Ursæ Majoris: It was stated by Mädler[1] that he found the companion to this bright star invisible on April 18, 1841. About an hour afterwards it was again visible, and he suggested that

[1] *Comptes Rendus*, vol. xiii., p. 438.

it is a variable of the Algol type. His account leaves it somewhat uncertain whether Alcor (the naked-eye companion) or the telescopic companion is referred to; but as he seems to have been using a telescope at the time, probably the close companion is intended. Alcor has also been suspected of variation in brightness.

γ Virginis: The components of this well-known binary star were thought by Struve to be alternately variable in brightness. His observations in 1851 and 1852 showed that sometimes the stars were exactly equal, and sometimes the southern star was from 0·2 to 0·7 magnitude brighter than the other. The period of variation would seem to be short, for Struve found the southern star half a magnitude brighter than the other on April 3, 1852, whereas on the 29th of the same month he found them 'perfectly equal.' The suspicion seems to be supported by the recorded measures of 'position angle,' some of which have been measured from one star, and some from the other, the brighter star being usually taken as the primary in measures of double stars.

A remarkable fact about variable stars in general is that very few of them show any parallax or proper motion, so that they probably lie at a great distance from the earth.

Method of Observation.—Variable stars form an interesting subject of study for the amateur observer. The method of observation is exceedingly simple. No instrument except a good opera-glass or binocular field-glass is necessary for the observation of the brighter variable stars when at or near their maximum brightness. Indeed, a few like Algol, *β* Lyræ, and *ζ* Geminorum may be observed with the naked eye through all their fluctuations of light. Mira Ceti, when at a bright maximum, may be best observed without any optical aid. For those variables, however, which do not rise above the fifth magnitude at maximum an opera-glass or binocular is necessary.

The best method of observing variable stars in order to determine the dates of their maxima or minima is that known as Argelander's. This method consists in estimating with the naked eye, or opera-glass if necessary, the difference in 'steps' or 'grades' between the variable, or suspected variable, and a comparison star near it, and not differing much from it in brilliancy. A 'step,' or smallest perceptible difference in brightness between two stars, is usually supposed to be about one-tenth of a magnitude. This differs, however, with different observers, but has generally a fixed, or nearly fixed, value for each individual. This value may be found by the observation of a number of stars whose magnitudes have been determined by photometric measurement. If, however, we compare the star under examination with one star slightly brighter and another slightly fainter, the magnitudes of the comparison stars being known, the absolute value of the observer's 'step' will be of no consequence. A number of comparison stars should be selected in the immediate vicinity of the variable, the selected stars being of various degrees of brightness, so that one or two are available for comparison with the variable in all stages of its light while it is visible with the naked eye or binocular. The stars compared with the variable on any particular night should not differ much from it in brightness. If possible, two comparison stars should be used—one a little brighter, and the other a little fainter, than the variable. Differences of more than five or six steps should, if possible, be avoided, as a larger difference cannot be estimated with any degree of certainty. Having selected two comparison stars, the observer then divides mentally the difference in light between the comparison stars into a number of steps. If the difference is about one magnitude or so, ten steps should be taken, but if the estimated or known difference is smaller, six, seven, or eight steps will be sufficient. The light of the variable is then estimated, and the observation recorded in the following way: If we call *a* and *b* the comparison stars, differing about one magnitude, and V the variable, *a* being brighter than *b*, and if V is judged to be midway in brightness between *a* and *b*, we write *a*5V5*b*. If V is slightly nearer in light to *a* than to *b*, we note *a*4V6*b*. If V is slightly nearer to *b*, we write *a*6V4*b*. We may also write *a*3V7*b*, or *a*7V3*b*, etc., as the case may be, the sum of the steps being always ten. If we estimate the difference between the comparison stars at, say, seven steps— a more desirable difference—we may write *a*2V5*b*, or *a*3V4*b*, or *a*5V2*b*,[1] as the case may be, the sum of the steps in this case being always seven. If the variable be estimated exactly equal to one of the comparison stars, we simply write $V = a$, or $V = b$, as the case may be. Some observers write $a > V$, or $a < V$, but this method should be carefully avoided, as it leads to confusion and ambiguity. Moreover, it is not Argelander's method. If a little map is made of the vicinity beforehand, and the comparison stars marked *a*, *b*, *c*, etc., an observation may be entered in the observing-book thus, 'Date; *a*4V6*b*3*c*; clear sky, no moon; 8·25 p.m.,' and the record is complete. The exact magnitude of the variable may then be easily found when the magnitudes of the comparison stars are known. In most cases the magnitudes of the comparison stars can be ascertained from the photometric catalogues of Harvard Observatory.

In making these estimates of magnitude, comparison

[1] If the comparison stars used are Flamsteed's or others, the figures representing the star should be placed in brackets to distinguish them from the steps. Thus: (72 Cygni) 3 (70) 3 (69); December 10, 1901.

stars should be taken (at the time of observation) having about the same altitude (if possible) above the horizon as the variable. Professor Pickering states that 'two stars apparently equal show a difference when placed one above the other,' the lower one being apparently the brighter. When comparing the relative brightness of two stars near each other, no attempt should be made to observe *both* stars simultaneously. Each should be looked at *directly*, and the eye passed rapidly from one to the other a number of times, so that the light of the star may fall on the same portion of the retina. Great stress is laid on this point by Argelander in his original paper on this method of observing 'the comparative brilliancy of stars,'[1] and as some observers seem to disregard Argelander's instructions, I will quote his words here. He says: 'Look *alternately* at the two stars which are to be compared, and endeavour to receive the image on that part of the eye in which it is seen the brightest. On the other hand, exercise the most zealous care not to look at both stars at once, for in such case the two can never be seen at once in their full brightness.' Only very clear nights should be used for making these observations, and care should be taken that none of the companion stars are dimmed by small fleecy clouds, which are often present in an otherwise clear sky. Argelander says: 'When the weather is misty, when clouds are flying, in bright twilight, or too close proximity to the moon, such observations should not be undertaken. It is especially important to avoid the impression of any other light, and when the moon is up to place one's self in such a position that the moon will be hid by some object. Before observing, the eye should

[1] Silliman's *American Journal*, vol. xix., 1885, p. 344; and Schumacher's *Jahrbuch* for 1844, p. 191.

be for some time accustomed to the darkness, in order that the pupil may be dilated as much as possible.'

The magnitudes of the comparison stars may in most cases be obtained from the catalogues of photometric measures made at Harvard Observatory; but for finding the time of maximum of a variable star the advantage of Argelander's method is that there is no necessity for the observer to know the actual magnitude of the comparison stars. By noting the difference in light between the variable and comparison stars each night, the actual time of maximum may be ascertained very accurately. And this is the most important thing to find in variable stars, for it enables us afterwards to ascertain the length of the period from maximum to maximum, which is the most important element to be determined. Some observers imagine that to observe variable stars accurately some form of photometer is necessary; but this is quite a mistake. All the best variable star observers now agree that for this work the eye itself is the best photometer. Indeed, a skilled observer can estimate the brightness of a star by the aid of good comparison stars with greater accuracy than can be obtained with any photometer. But, of course, to obtain such a result considerable experience is necessary.

Some observers in estimating star magnitudes by the method above described put the opera-glass or telescope slightly out of focus, and consider that in this way the effect of a star's colour on the eye is to a great extent eliminated. With reference to this method, Dr. Gould remarked ('Uranometria Argentina,' p. 452, note to l Carinæ): 'The results are not very satisfactory, owing in part to the circumstance that many of the comparisons were made by putting the opera-glass out of focus, a method which our experience shows not to give results in accordance with estimates by the method of sequences or by comparisons with artificial stars of measurable brilliancy.' The present writer fully agrees with this opinion, and has always found that the best results are obtained by accurately focussing the instrument used. For all the brighter stars no instrument whatever is necessary, naked-eye observations being in this case the best of all. This applies to all stars down to, say, the fourth magnitude.

CHAPTER IV

STAR CLUSTERS AND NEBULÆ

Globular Clusters — Irregular Clusters — Irregular Nebulæ — Spiral Nebulæ — Planetary Nebulæ — Annular Nebulæ—Nebulous Stars.

Globular Clusters. — The term 'globular cluster' is applied to those clusters of stars which evidently occupy a space of more or less globular form. They have been aptly termed 'balls of stars,' and are among the most interesting objects in the heavens. There are some fine examples in both hemispheres, and they usually contain hundreds, and in some cases even thousands, of small stars.

The following are among the most remarkable globular clusters. They are given in order of right ascension, and the positions are for 1900·0.

47 Toucani: 0 h. 19·6 m., S. 72° 39′. It lies closely west of the smaller 'Magellanic Cloud' in the Southern Hemisphere, and, with the exception of ω Centauri, is, perhaps, the finest globular cluster in the sky. It is thus described by Sir John Herschel: 'A most magnificent globular cluster. It fills the field with its outskirts, but within its more compressed part I can insulate a tolerably defined circular space of 90″ diameter, wherein the compression is much more decided, and the stars seem to run together; and this part I think has a pale pinkish or rose colour . . . which contrasts evidently with the white

light of the rest. . . . The stars are equal, fourteenth magnitude, immensely numerous and compressed. . . . It is *comparatively insulated.* After it has passed, the ground of the sky is perfectly black throughout the whole breadth of the sweep . . . condensation in three distinct stages. . . . A stupendous object.' Dr. Gould called it 'one of the most impressive, and perhaps the grandest of its kind, in either hemisphere.' According to Professor Bailey, who photographed the cluster at Arequipa, Peru, the number of stars it contains is about 1,500. Among these he found three variable stars, and three more were found by Mrs. Fleming.

ω Centauri: 13 h. 20·8 m., S. 46° 57′. A magnificent globular cluster—the finest in the heavens. Clearly visible to the naked eye as a hazy star of the fourth magnitude. It was described by Sir John Herschel as 'beyond all comparison the richest and largest object of its kind in the heavens. The stars are literally innumerable. . . . All clearly resolved into stars of two magnitudes, viz., thirteenth and fifteenth, the larger lying in lines and ridges over the smaller. The larger stars form rings like lacework on it. . . . Altogether this object is truly astonishing.' This marvellous object has been photographed by Sir David Gill at the Royal Observatory, Cape of Good Hope, and also at Arequipa, Peru, by Professor Bailey. On the latter photograph the individual stars can be distinctly seen and counted. The enumeration has been made by Professor and Mrs. Bailey, and the result is 6,387. Professor Pickering thinks, however, that the actual number in the cluster is about 5,050, some of those counted being really outside the cluster itself. Two variable stars have been found in this cluster.

Messier 3: 13 h. 37·6 m., N. 28° 53′. A fine globular cluster with outliers, in Canes Venatici, about 12° north-west of Arcturus. Sir William Herschel with his twenty-feet reflector found it 'a beautiful cluster of stars 5′ or 6′ in diameter.' Sir John Herschel described it as very large and very bright, with stars of eleventh to fifteenth magnitude. A photograph by Dr. Roberts (taken in May, 1891) 'confirms the general description of previous observers.' No less than 132 variable stars have been detected among the outlines of this cluster.

Messier 5 : 15 h. 13·5 m., N. 2° 27′. A globular cluster lying close to the fifth magnitude star 5 Serpentis. Sir William Herschel estimated the number of stars at 200, but it contains many more. A photograph by Dr. Roberts shows the stars to the fifteenth magnitude. No less than 85 variable stars out of 750 have been detected among the outliers of this cluster.

Messier 13 : 16 h. 38·1 m., N. 36° 37′. This is the well-known globular cluster in Hercules. It lies between the stars η and ζ Hercules, and is considered to be one of the finest of its class. It was discovered by Halley in 1714. Sir William Herschel described it as 'a most beautiful cluster of stars, exceedingly compressed in the middle, and very rich.' He estimated the number of stars at 14,000, but the real number is probably not so large. From a photograph taken in America by Mr. H. K. Palmer, with an exposure of two hours, he finds the number to be 5,482, of which 1,016 are 'bright' and 4,466 'faint.' Lord Rosse found three dark streaks or lanes, which were also seen by Buffham. The existence of these dark lanes is confirmed by photographs taken by Dr. Roberts in 1887 and 1895, and they are also visible in Palmer's photograph. Dr. Roberts thinks that the cluster was probably evolved from a spiral nebula.

Messier 92 : 17 h. 41·1 m., N. 43° 15′. In a rather blank space in Hercules, about 6° north of π Herculis. Sir W. Herschel found it a brilliant cluster, 7′ or 8′ in diameter. Sir John Herschel described it as a globular cluster, very bright and large, and well resolved into small stars. Webb says it is a 'very fine cluster, though not equal to M. 13 ; less resolvable, intensely bright in centre.' It has been photographed by Dr. Roberts.

Messier 22 : 18 h. 30·3 m., S. 23° 29′. About midway between μ and σ Sagittarii. Sir John Herschel describes it as 'a globular cluster, very bright, very large, very much compressed, 7′ diameter. The stars are of two magnitudes, fifteenth to sixteenth and twelfth ; and what is very remarkable, the largest of the latter are visibly reddish.' Webb found it 'very interesting from visibility of components, tenth and eleventh magnitude, which makes it a valuable object for common telescopes, and a clue to the structure of many more distant or difficult nebulæ.' Observing with a three-inch telescope in the Punjab the present writer found the larger stars well seen. The greater portion of the cluster is, however, nebulous with this aperture.

Messier 55 : 19 h. 32 m., S. 31° 13′. Described by Sir John Herschel as 'a fine large, round cluster; 6′ diameter; all clearly resolved into stars of eleventh, twelfth, and thirteenth magnitude.' Observing with a three-inch refractor in the Punjab, the present writer saw glimpses of stars in it with a low power; it will not bear a high power with this aperture; very much like, but not so bright as Messier 13 in Hercules.

Messier 15 : 21 h. 25·1 m., N. 11° 43′. A globular cluster in Pegasus, in a comparatively vacant space about 4° north-east of the star δ Equulei. It was discovered by Maraldi in 1745. Sir William Herschel resolved it into stars, and Sir John Herschel estimated them about fifteenth magnitude. A photograph by Dr. Roberts 'confirms the general description' and shows the stars 'arranged in curves and patterns.'

Messier 2 : 21 h. 28·3 m., S. 1° 15′. A globular cluster of 5′ or 6′ in apparent diameter, situated in Aquarius about 5° north of the star β Aquarii. Sir William Herschel with his forty-feet telescope could see the individual stars even in the centre of the cluster, and Sir John Herschel compared it to 'a heap of white sand.' The stars are very faint, probably not above the fifteenth magnitude. Seen as a star, it was measured 7·69 magnitude at Harvard.

Irregular Clusters.—These are of an irregular shape and show no approach to the globular form. There are many fine examples of this class of star cluster.

The following are some fine specimens:

H VI, 33, 34 Persei: R.A. 2 h. 12 m. and 2 h. 15·4′, N. 56° 41′ and 56° 39′. This is the 'double cluster near χ Persei, two magnificent clusters in the sword hand of Perseus,' and forming, as Smyth says, 'one of the most brilliant telescopic objects in the heavens.' They have been photographed at the Paris Observatory, and also by Dr. Roberts. May be well seen with a three-inch telescope.

The Pleiades: 3 h. 41·5 m., N. 23° 48′.[1] The well-known

[1] The place given is that of η Tauri, or Alcyone.

naked-eye cluster—probably familiar to most people. Viewed with an opera-glass, it forms a good example of the appearance of a bright telescopic cluster as seen in a telescope. A photograph taken at the Paris Observatory in 1885, with three hours' exposure, shows about 2,326 stars down to the seventeenth magnitude. More recent photographs, however, show that the surrounding sky is *quite* as rich in *faint* stars as the cluster itself. We may therefore conclude that most of the faint stars apparently connected with the Pleiades do not really belong to the cluster itself, but probably lie behind it in space. The conclusion to which some astronomers have been led, viz., that the Pleiades cluster contains stars differing enormously in real size, seems, therefore, quite fallacious. Most of the faint stars, which it *apparently* contains, have probably no connection whatever with the brighter stars which form the group visible to the naked eye. The existence of a considerable amount of nebulous matter apparently involved in the cluster has been disclosed by photography in recent years. Of 91 stars observed with the spectroscope at Harvard Observatory, 59 were found to be of type A, 8 of E, 14 of F, 1 of G, 8 of H, and 1 of type K.

Messier 37 : 5 h. 45·7 m., N. 32° 31′. About midway between κ and ϕ Aurigæ. Sir John Herschel describes it as a rich cluster, with large and small stars. Smyth called it 'a magnificent object, the whole field being strewed as it were with sparkling gold-dust, and the group is resolvable into 500 stars from the tenth to the fourteenth magnitude besides the outliers.' These descriptions are confirmed by a photograph taken by Dr. Roberts, in which the stars are shown down to about the sixteenth magnitude. The surrounding region is pretty rich in stars.

Messier 35 : 6 h. 2·7 m., N. 24° 21′. A little north-west of the star η Geminorum. Just visible to the naked eye in a clear sky. It is a large rich cluster of stars about ninth to sixteenth magnitude. Lord Rosse called it 'magnificent,' and Lassell spoke of it as 'a marvellously striking object.' On a photograph taken by Dr. Roberts in February, 1893, he 'counted 620 stars in the cluster within a circle of 26′ of arc in diameter.' But a glance at the photograph shows that it is not nearly so rich in stars as the globular clusters.

Messier 41 : 6 h. 42·7 m., S. 20° 38′. About 4° south of Sirius. Just visible to the naked eye. Messier described it as a mass of small stars. Webb says : 'Superb group. . . . Larger stars in curves with ruddy star near centre,' which Espin suspects to be variable.

Messier 46 : 7 h. 37·2 m., S. 14° 35′. A little west of the star 2 Puppis. Sir John Herschel described it as 'a superb cluster of stars, twelfth to sixteenth magnitude.' It includes a planetary nebula (Herschel), which Lassell, Lord Rosse, and Dr. Roberts found to be annular. The cluster is about half a degree in diameter, or the apparent size of the full moon. A photograph by Dr. Roberts, taken in February, 1894, shows it to be a rich cluster with stars down to the seventeenth magnitude in a region 'densely crowded with stars.'

Messier 44 : 8 h. 34·3 m., N. 20° 21′. This is the Præsepe of the old astronomers in the constellation Cancer. A scattered cluster to the naked eye : 36 stars were counted in it by Galileo, but, of course, there are many more.

κ Crucis : 12 h. 47·9 m., S. 59° 50′. A reddish star of the sixth magnitude near β Crucis (one of the bright stars in the Southern Cross), accompanied by a fine cluster of small stars. It is described by Sir John Herschel as 'a most vivid and beautiful cluster of 50 to 100 stars. Among the larger there are one or two evidently greenish ; south of the red star is one of thirteenth magnitude, also red, and near it one of twelfth magnitude, bluish . . . no nebula is perceptible in any part of the extent of this cluster, which, though neither a large nor a rich one, is yet an extremely brilliant and beautiful object when viewed through an instrument of sufficient aperture to show distinctly the very different colours of its constituent stars, which gives it the effect of a superb piece of fancy jewellery.'

Messier 24 : 18 h. 12·6 m., S.18° 27′. About 2° north of μ Sagittarii. Sir John Herschel described it as pretty large and very rich, with stars of eleventh to twentieth magnitude.[1] Lord Rosse saw some unresolved nebulous light, but a photograph by Dr. Roberts shows the stars free from nebulosity. On this

[1] Sir John Herschel's 'twentieth magnitude' stars are really much brighter. Probably not fainter than fifteenth magnitude.

photograph the streams of stars surrounding the centre seem to be arranged in spirals, and suggest the idea that the cluster has been evolved from a spiral nebula.

Messier 11: 18 h. 45·7 m., S. 6° 23′. Just visible to the naked eye in the so-called 'Shield of Sobieski,' which forms the southern portion of Aquila. It was discovered by Kirch in 1681. Sir William Herschel saw it divided into five or six groups of stars of about the eleventh magnitude. Admiral Smyth compared it to 'a flight of wild ducks,' and says it is 'a gathering of minute stars, with a prominent eighth magnitude in the middle, and two following.' A photograph taken by Dr. Roberts agrees well with the descriptions, and shows that the cluster is free from nebulosity.

Messier 71: 19 h. 49·3 m., N. 18° 31′. Between γ and δ Sagittæ. Sir John Herschel describes it as a very rich cluster, with stars of eleventh to sixteenth magnitude. A photograph by Dr. Roberts shows a cluster in which the curves and arrangement of stars closely resemble those in a spiral nebula. 'The surrounding region is densely crowded with stars down to the seventeenth magnitude, arranged in remarkable curves and lines, which are very suggestive of having been produced by the effects of spiral movements.'

Under the head of irregular clusters, we may mention the Magellanic clouds, which are two spots of Milky Way light visible to the naked eye in the Southern Hemisphere. These spots, also known as the *nubecula major* and *nubecula minor*, are roughly of a circular form. The larger 'cloud' covers over forty-two square degrees, and when examined with a telescope is found to consist of upwards of 600 stars of the sixth to the tenth magnitude, with numerous fainter ones, and nearly 300 clusters and nebulæ. The smaller Magellanic cloud, or *nubecula minor*, is fainter to the eye, and not so rich in the telescope. It covers about ten square degrees, and it is described by Sir John Herschel[1] as 'a fine, rich, large cluster of very small stars of twelfth to eighteenth magnitude, which fills more than many fields, and is broken into many knots, groups, and straggling branches, but the *whole* (*i.e.*, the whole of the clustering part)

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[1] *Cape Observations*, p. 145.

is clearly resolved.' It is surrounded by a barren region, remarkably devoid of stars. Sir J. Herschel says: 'The access to the *nubecula minor* on all sides is through a desert.' 'It is preceded at a few minutes in R.A. by the magnificent globular cluster 47 Toucani (Bode)'—already described—'but it is completely cut off from all connection with it; and with this exception its situation is in one of the most barren regions in the heavens.'

Irregular Nebulæ.—Under this head may be classed those nebulæ which have no definite shape, but are cloudlike in appearance when examined with the telescope. They are shown by the spectroscope to consist of nothing but glowing gas, the chief constituents being hydrogen and an unknown substance now called 'nebulum.' The most remarkable of these visible in northern latitudes is that known as the Great Nebula in Orion, which surrounds the star θ Orionis in 'the sword.' It is visible in any small telescope, or even with a binocular field-glass. There are many telescopic objects of a similar character.

The following are some interesting examples of irregular nebulæ:

Messier 1: 5 h. 28·5 m., N. 21° 57′. Known as the Crab Nebula. About 1° north-west of ζ Tauri. It was first seen by Bevis in 1731, and again by Messier in 1758, while observing the comet of that year. Its rediscovery induced him to form his catalogue of nebulæ, to help observers in distinguishing these objects from comets. Lord Rosse's great telescope is said to have partially resolved it into stars, but photographs taken by Dr. Roberts show a very nebulous appearance, and with but little of the 'crablike' appearance depicted in Lord Rosse's drawing. Dr. Roberts speaks of 'some starlike condensations involved in the nebulosity.'

Messier 42: 5 h. 30·4 m., S. 5° 27′. This is the Great Nebula in Orion referred to above. It surrounds the multiple star θ Orionis. It seems to have been discovered by Cysat in

1618, and a drawing of it was published by Huygens in 1659. Galileo does not mention it, although he paid especial attention to Orion. It is visible in an opera-glass as a spot of milky light, and its general outline may be seen with a good three-inch telescope. Near the centre are four stars close together, which form 'the trapezium' of telescopists already referred to under the head of Multiple Stars. Numerous small stars are scattered over the surface of this great nebula, which was at one time considered by Lord Rosse to show symptoms of being resolvable into small stars when seen with his large telescope. The spectroscope, however, shows it to be glowing gas, consisting of hydrogen and some unknown substance. From his spectroscopic observations of this nebula, Sir W. Huggins thinks that the 'stars of the trapezium are not merely optically connected with the nebula, but are physically bound up with it, and are very probably condensed out of the gaseous matter of the nebula.' There appear to be no grounds for considering this nebula to be an external galaxy. The nebula has been frequently drawn, and it has been successfully photographed by Common, Roberts, and others.

30 Doradus: 5 h. 39 m., S. 69° 10′. Situated in the larger Magellanic cloud. Sir John Herschel describes it as 'one of the most singular and extraordinary objects which the heavens present.' It is sometimes called the 'looped nebula,' from the curious convolutions formed by its nebulous rays and streams. Near its centre is a pear-shaped opening, like the 'keyhole' vacuity in the Great Nebula in Argo.

N.G.C. 2237-39: 6 h. 27 m., N. 5° 0′. Near 12 Monocerotis. A large extent of nebulosity, measuring about 77′ by 67′, which is described by Dr. Roberts from a photograph as 'a cloudy mass broken up into wisps, streams, and curdling masses densely dotted over with stars, which also extend widely over the regions surrounding. There are many dark areas with few, if any, stars in them. . . . Some remarkable black tortuous rifts meander through the nebulosity in the *north preceding* half of the nebula.'

The Great Nebula in Argo: 10 h. 41·2 m., S. 59° 9·5′.[1] A

[1] The position is that of the variable star η Argus, which is involved in the nebula.

magnificent nebula, which covers a space in the heavens about five times as large as the full moon. It has a curious 'keyhole'-shaped vacuity near the centre, and the wonderful variable star η Argus (already described) is apparently situated in the densest part of the nebulosity. The nebula shows no signs of being resolvable into stars, and, like the Great Nebula in Orion, the spectroscope shows it to consist of glowing gas.

Messier 20: 17 h. 56·3 m., S. 23° 2′. The Trifid Nebulæ. It lies closely north of the star 4 Sagittarii. A very curious object, with three dark lanes radiating from the centre. It has been well drawn by Sir John Herschel and Trouvelot, and it has been photographed by Dr. Roberts[1] and at the Lick Observatory. Dr. Roberts' photograph shows the dark rifts very distinctly, and these rifts are free from stars. Although it has a very nebulous appearance, the spectrum seems to be *not* gaseous. A triple star seen by Sir John Herschel in the middle of one of the dark lanes is now *in* the edge of the nebula itself. It seems, therefore, that the nebula has moved since Herschel's time.

Messier 8: 17 h. 57·6 m., S. 24° 22′. A very fine object in the Milky Way, in Sagittarius; a little south of the Trifid Nebula. Visible to the naked eye. A beautiful drawing of it, showing nebulous streaks and loops, is given by Sir John Herschel in his *Cape Observations*, and he calls it 'a superb nebula.' There are many stars in the field. Tempel, in 1877, found marked changes in the nebula compared with the stars, which are nearly in the same relative positions as when observed by Herschel. A photograph taken by Dr. Roberts in July, 1899, shows that there are 'many stars of between the eighth and seventeenth magnitude either involved or seen in projection upon the nebula, and on the following side they resemble a cluster of bright stars,' but he does 'not think they are physically connected with it; they are probably between the earth and the nebula.' The present writer found it plainly visible to the naked eye in the Punjab sky, and a glorious object even with a three-inch refractor. It is followed by a fine cluster which lies between two eighth magnitude stars. Secchi found the spectrum that of a gaseous nebula.

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[1] *Knowledge*, February, 1900.

Messier 16: 18 h. 13·2 m., S. 13° 50′. South of Sobieski's Shield. Sir John Herschel describes it as a cluster containing at least 100 stars, but a photograph by Dr. Roberts shows that it is really 'a large bright *nebula* with a cluster apparently involved in it.'

Spiral Nebulæ.—These are among the most marvellous and interesting objects in the heavens. They were discovered by the late Earl of Rosse with his giant six-foot telescope, and their spiral character has been fully confirmed by photography in recent years. Indeed, photography has shown many nebulæ to be spiral which had not previously been recognised as belonging to this interesting class. A very large number of new nebulæ were discovered by the late Professor Keeler at the Lick Observatory with the Crossley three-foot reflector. He found that probably one-half of these are spiral, and that 'any small, compact nebula not showing evidence of spiral structure appears exceptional.' The spectroscope shows that these wonderful objects are *not* gaseous. They are probably partly condensed into the liquid or solid form.

The following are some remarkable examples of spiral nebulæ:

Messier 31: 0 h. 37·3 m., N. 40° 43′. This is the Great Nebula in Andromeda. It is plainly visible to the naked eye near the star ν Andromedæ, and forms quite a conspicuous object even with a binocular field-glass. It is mentioned by Al-Sufi, the Persian astronomer, as a familiar object in the tenth century. It is of a very elongated form, and much brighter in the centre. Although the most powerful telescopes have failed to resolve it into stars, the spectroscope shows that it is *not* gaseous. Photographs by Dr. Roberts seemed at first to show that it consisted of a nucleus surrounded by *rings*, but his later photographs prove that it is really 'a left-hand spiral, and not annular.' Two small nebulæ lie near it, one completely separated from the Great Nebula, and the other touching its borders; and we apparently see in this wonderful object a stellar system in process of formation from the nebulous stage. The sudden appearance of a small star near the nucleus in August, 1885, has already been referred to under the head of Temporary Stars.

Messier 33: 1 h. 28·2 m., N. 30° 9′. Between α Arietis and β Andromedæ, nearer the latter star. It was described by Sir John Herschel as a remarkable object, extremely large, round, and very rich, and resolvable into stars, but a photograph by Dr. Roberts shows it to be really a right-hand spiral nebula. There is a nucleus of 'dense nebulosity,' with about twenty stars involved, and the other parts of the nebula contain hundreds of nebulous stars of about sixteenth or seventeenth magnitude. It is of considerable apparent size, measuring about 1° long by ½° in width.

Messier 74: 1 h. 31·3 m., N. 15° 16·3′. A little east of η Piscium. Sir John Herschel thought it was a globular cluster, partially resolved into stars, but Lord Rosse found it to be a spiral nebula, and a photograph by Dr. Roberts shows it 'to be a very perfect right-hand spiral, with a central stellar nucleus and numerous starlike condensations in the convolutions of the spiral.'

Messier 99: 12 h. 13·7 m., N. 14° 58′. A little south-east of the star 6 Comæ. Sir John Herschel described it as 'a very remarkable object, bright, large, and round.' Lord Rosse found it to be a wonderful spiral. Key thought it resolvable with an eighteen-inch reflector, and so did d'Arrest. A photograph by Dr. Roberts confirms its spiral character, and shows 'many starlike condensations in the convolutions.'

Messier 100: 12 h. 17·9 m., N. 16° 23′. About 2° north-east of 6 Comæ Berenices. Discovered by Méchain in 1781. Smyth thought it 'globular,' but Lord Rosse found it to be a spiral, with the centre a planetary nebula. A photograph by Dr. Roberts shows it to be a 'strikingly perfect' spiral with a 'sharply stellar nucleus in the midst of faint nebulosity.'

Messier 51: 13 h. 25·7 m., N. 47° 43′. This is the great spiral nebula in Canes Venatici. It lies about 3° south-west of η Ursæ Majoris. Sir John Herschel described it as a double nebula, the larger with a nucleus and a ring round it. Admiral Smyth thought it resembled 'a ghost of Saturn with its ring in a vertical position.' Its spiral character was discovered by Lord Rosse, and his drawing agrees well in general outline with photographs taken by Dr. Roberts and Dr. W. E. Wilson. Dr. Roberts finds 'both nuclei of the nebula to be stellar, surrounded by dense nebulosity, and the convolutions of the spiral in this, as in other spiral nebulæ, are broken up into star-like condensations with nebulosity around them.' Sir William Huggins finds that the spectrum is *not* gaseous. This seems to be the case in all the spiral nebulæ, and shows that they are in a more advanced stage of evolution than the Great Nebulæ in Orion and Argo.

Messier 101: 13 h. 59·6 m., N. 54° 50′. About 5° east of ζ Ursæ Majoris. Sir John Herschel described it as pretty bright, very large, and irregularly round. Lord Rosse found it to be spiral, 14′ in diameter, and his drawing agrees fairly well with a photograph taken by Dr. Roberts, which shows 'a well-defined stellar nucleus, with the usual convolutions and starlike condensations.'

Planetary Nebulæ.—These are a remarkable and interesting class of nebulæ. They were so named by Sir William Herschel from their resemblance to planetary discs. This supposed resemblance applies only to their general uniformity of brightness and to the absence of any definite nucleus or brighter portion—at least, when seen with telescopes of moderate power. Their intrinsic brilliancy is, of course, far inferior to that of the planets, being usually faint objects, and only to be seen well with telescopes of considerable power. About three-fourths of the known planetary nebulæ are situated in the Southern Hemisphere, but there are some interesting examples north of the Equator. A bluish colour seems to be a characteristic of these planetary nebulæ.

The following are some of the most interesting examples of this class:

h 3163: 9 h. 18·7 m., S. 57° 53′. Between *g* and *h* Carinæ. Sir John Herschel says: 'Beautifully round and sharp; just like a small planet 3′ or 4′ in diameter. . . . The finest planetary nebula I ever remember to have seen for sharpness of termination.'

H IV. 27: 10 h. 20 m., S. 18° 8′. About 2° south of the star μ Hydræ. Described by Admiral Smyth as resembling Jupiter in 'size, equable light, and colour.' Sir John Herschel speaks of its colour as 'a decided, at all events a good, sky blue.' Huggins finds a gaseous spectrum. As a star it was measured 7·94 magnitude at Harvard.

Messier 97: 11 h. 9 m., N. 55° 34′. About 2° south-east of β Ursæ Majoris. It was described by Sir John Herschel as a remarkable planetary nebula, very large and round, about 160″ of arc in diameter. Lord Rosse compared it to the face of an owl, on account of two holes in the centre, and it has since been known as the 'Owl Nebula.' A photograph by Dr. Roberts shows it of an elliptical shape, about 203″ in diameter, with a fifteenth magnitude star in the centre, but no other star in the nebula. He says: 'The star seen by both Lord Rosse and Dr. Robinson has disappeared.' Sir William Huggins finds the spectrum gaseous.

h 3365: 11 h. 45·3′, S. 56° 37′. Between π Centauri and δ Crucis—nearer the latter. Sir John Herschel says: 'Perfectly round, very planetary; colour fine blue; a very little ill-defined at the edges; has no "satellite stars"; very like Uranus, only about half as large again and blue. . . . It is of a most decided independent blue colour when in the field by itself, and with no lamp-light and no bright star. About 10′ north of it is an orange-coloured star, eighth magnitude. When this is brought into view the blue colour of the nebula becomes intense . . . colour a beautiful rich blue, between Prussian blue and verditter green. . . . Total light of nebula equal to a star of sixth or sixth and a half magnitude.'

Struve 5 N: 16 h. 40·3 m., N. 23° 59′. Between β Herculis and 51 Herculis—nearer the latter star. D'Arrest estimated it at eighth magnitude. Webb calls it 'very bright, not sharply defined, like a star out of focus.' Lord Rosse saw it of an intense blue colour. Secchi thought it resolvable into stars, but Huggins finds a gaseous spectrum.

H IV. 37 : 17 h. 58·6 m., N. 66° 38′. Near the pole of the Ecliptic and between ω and 36 Draconis. Webb saw it 'as a very luminous disc, much like a considerable star out of focus.' Smyth describes it as 'a remarkably bright and pale blue object.' It may be well seen with a telescope of four inches aperture. Examined with the great Lick telescope, Holden found it an object of extraordinary structure. He says it 'is apparently composed of rings overlying each other, and it is difficult to resist the conviction that these are arranged in space in the form of a true helix.' Huggins found the spectrum gaseous.

N.G.C. 6572 : 18 h. 7·2 m., N. 6° 48′. About 2° south of the star 71 Ophiuchi. A small but very bright planetary nebula, which Struve thought 'one of the most curious objects in the heavens.' It has a gaseous spectrum.

Messier 27 : 19 h. 55·3 m., N. 22° 37′. 'The Dumb-bell' Nebula. A little south of the star 14 Vulpeculæ. It may perhaps be included in this class, although its form is not exactly that of a planetary disc. It has been drawn by Sir John Herschel, D'Arrest, Lord Rosse, and Lassell. At one time Lord Rosse thought it might be resolvable into stars, but Huggins found a gaseous spectrum. Photographs by Dr. Roberts and Dr. Wilson show that it is really a globular mass surrounded by a broad and darker ring, which cuts off some of the light and gives it the dumb-bell appearance.

H IV. 1 : 20 h. 58·7 m., S. 11° 46′. Discovered by Sir William Herschel in 1782. About 1½° west of the star ν Aquarii. One of the finest specimens of the class. Viewed in a large telescope, a projection on each side gives it an appearance somewhat like Saturn, with the rings seen edgeways. The great Lick telescope shows it to be a wonderful object: 'a central ring lies upon an oval of much fainter nebulosity.' Holden says the colour is a pale blue, and he compared the appearance of the central ring 'to that of a footprint left in the wet sand of a sea-beach.' Huggins finds a gaseous spectrum.

Annular Nebulæ. — There are nebulæ which are, apparently at least, shaped like a ring. They form a rare type, only a few objects of the kind being known in the whole heavens. They seem to be all gaseous.

The following are some interesting specimens of this class :

H IV. 39 : 7 h. 37·3 m., S. 14° 30·4′. It lies in the cluster Messier 46 (already described among the irregular clusters). It was described by Sir John Herschel as 'a planetary nebula,' but a photograph by Dr. Roberts, taken in February, 1894, shows it 'to be annular in form, strongly resembling M 57 Lyræ.'

h 3680 : 17 h. 15·4 m., S. 38° 23′. A little south-west of υ Scorpii. Sir John Herschel describes it as 'a delicate, extremely faint, but perfectly well-defined annulus. . . . The field crowded with stars, two of which are on the nebula. A beautiful delicate ring of a faint, ghost-like appearance, about 40″ diameter in a field of about 150 stars, eleventh and twelfth magnitude and under.'[1]

Messier 57 : 18 h. 49·9 m., N. 32° 54′. Between β and γ Lyræ. It is of a somewhat oval form, and the central portion is not quite dark, but filled in with faint nebulous light. It may be seen in comparatively small telescopes. Lord Rosse, Chacornac, and Secchi thought it resolvable into stars, but Huggins finds a gaseous spectrum. There is a very faint star in the centre.

Nebulous Stars.—These are stars surrounded by a nebulous haze or atmosphere. This nebulous envelope must be of enormous size to be visible at the great distance of the stars from the earth.

Nebulous stars are rare objects. The following are some of the most remarkable :

Orionis : 5 h. 30·5 m., S. 5° 59′. A triple star surrounded by a nebulous haze.

ε Orionis : 5 h. 31·1 m., S. 1° 16′. The middle star in Orion's 'belt,' involved in an immense nebulous atmosphere.

H IV. 45 : 7 h. 23·3 m., N. 21° 7′. Near 61 and 63 Geminorum. Sir John Herschel described it as an eighth magnitude

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[1] *Cape Observations*, p. 114.

star 'exactly in the centre of an exactly round bright atmosphere 25″ in diameter.' Lord Rosse saw it as a star surrounded by a dark and then by a luminous ring. Burnham, who classes it as a planetary nebula, describes it as 'one of the most beautiful objects of the kind in the heavens.' The spectroscope shows it to be gaseous.

h 3121 : 8 h. 31·8 m., S. 40° 19′. Sir John Herschel described it as an eighth or ninth magnitude star 'involved in a pretty bright, round nebula . . . a decided and perfectly unequivocal nebula. . . . Diameter 3′.'

h 3548 : 13 h. 51·7 m., S. 39° 30′. About 2° north of ϕ Centauri. Sir John Herschel describes it as 'a close double star, involved in a very large, bright, luminous atmosphere, 2′ diameter. . . . It is no illusion ; other stars are sharp and brilliant, and have not the least nebulous appearance.'

Some of the long-period variable stars seem to be surrounded by nebulous envelopes. This has been seen by Grover in the case of R, S, and T Cassiopeiæ, R Cygni, S Herculis, S Coronæ, S Cephei, and T Draconis, when the variable is at or near its minimum light. At maximum the light of the star is generally sufficient to obliterate the nebulosity.

Star clusters are chiefly found in the Milky Way. The gaseous nebulæ crowd towards the poles of the Galaxy. There are, however, some exceptions to this rule.

CHAPTER V

THE STELLAR UNIVERSE

The Milky Way—The Stellar Universe—The Nebular Hypothesis

The Milky Way.—The nebulous-looking band or zone of faint light known as the Milky Way, or Galaxy, is probably familiar to the most casual observer, and on a clear, moonless night forms a conspicuous object in the nocturnal heavens. It has attracted the attention of astronomers and philosophers from the earliest ages of antiquity, and various hypotheses have been advanced to account for its appearance. Plutarch saw in it, or pretended to see, the marks of Phaeton's accident. Anaxagoras, strange to say, thought it was the shadow of the earth! but why a shadow should be luminous he does not explain. Aristotle thought it was due to atmospheric vapours (!)—another wild hypothesis. Other equally absurd ideas were entertained by the ancients, but the true theory, namely, that its light is due to myriads of small stars—too faint to be individually visible to the naked eye—was, however, advanced by Democritus, Manilius, and Pythagoras, and the invention of the telescope fully confirmed the truth of this hypothesis.

A little attention will show that the Milky Way very nearly follows the course of a 'great circle' of the star sphere, a fact which implies that the sun and solar system lie in or close to the general plane of the Galaxy. The mean centre line of the luminous band is inclined to the Equator at an angle of about 65°, and intersects that circle at about 7 hours and 19 hours of right ascension. The position of the North Pole of the Milky Way has been given as follows:

	R.A.	*North Declination.*
Sir John Herschel...	12 h. 47 m.	27°
Heis...	12 h. 41·2 m.	27° (1880)
Houzeau	12 h. 49 m.	27½°
Gould	12 h. 41 m. 20 s.	27° 21′ (1875)

These results are in close agreement, and place the pole in the constellation Coma Berenices, a little south of the star Flamsteed 31. The south pole is in R.A. 0 h. 47 m., S. 27°.

Various representations of the Milky Way are given in star atlases, such as Proctor's and others, but these merely afford a general idea of its appearance, and show no details of the brightness or faintness of its various parts—features which are very obvious when carefully observed. A mere casual glance might lead an observer to suppose that the Galaxy stretched as a band of nearly uniform brightness across the heavens. But good eyesight, careful attention, and a clear sky will soon disclose numerous details previously unsuspected—streams and rays of different brightness, intersected by rifts of darkness and interspersed with spots and channels of comparatively starless spaces.

An attempt was made by Heis and Houzeau in their maps to delineate this varying brightness, but their drawings—especially that of Houzeau—are deficient in detail and merely show the principal features. Gould's drawing of the Milky Way in the Southern Hemisphere is, however, more elaborate. Careful drawings have been made by Boeddicker and Easton, which show a wealth of detail, but, unfortunately, do not agree exactly. Probably photography will eventually give us a more reliable picture.

It was pointed out by the late Mr. Proctor several years since that even the brighter stars show a marked tendency to crowd on the Milky Way, thus implying a real, and not merely an apparent, connection between the lucid stars and the faint stars composing the Galaxy. This conclusion has, I believe, been doubted or denied by some astronomers. It has, however, I think, a real foundation in fact, and to test its reality I examined some years ago the position of all the stars in both hemispheres down to the fourth magnitude, as given in the Harvard and Oxford photometries and in Gould's 'Uranometria Argentina.' The most correct *general* representation of the Milky Way, as seen in Northern latitudes, hitherto published is probably that given in Heis's Atlas. An examination of this drawing will show that most of the dark spaces, or 'coal-sacks,' shown in Proctor's Atlas and other star maps are, according to Heis, filled in with faint nebulous light, and are merely dark in comparison with the surrounding luminosity. This is especially the case with reference to the openings in Cygnus, which form a remarkable feature in most star maps, but which Heis shows to be really filled in with nebulous light.

I followed Heis's delineation of the Milky Way for the portion of the heavens down to about 35° south declination, and for the regions further south that given by Sir John Herschel in the *Cape Observations*. I find that the following bright stars lie on the Milky Way, or on faint nebulous light connected with it: Of those brighter than second magnitude, Vega, Capella, Altair, α Orionis, Procyon, α Cygni, α Persei, Sirius, α and β Centauri, α and β Crucis—or a total of 12 stars out of 32. Of those brighter than third magnitude, we have γ Geminorum; β, γ, and δ Cassiopeiæ; γ, δ, and ϵ Cygni; α Cephei; γ Aquilæ; ϵ, θ, κ, λ, π, and τ Scorpii; γ Crucis; δ Velorum; δ, γ, ϵ, σ and λ Sagittarii; η Ophiuchi; θ and ι Carinæ; ζ Puppis; κ, λ, and

μ Velorum ; π Puppis ; η Canis Majoris ; α Aræ ; and α Muscæ—or a total of 33 stars out of 99. Of those between third and fourth magnitude, I find 73 stars on the Milky Way out of 262, or a grand total of 118 stars out of 392 stars above the fourth magnitude, or 30·1 per cent. Considering the stars north and south of the Equator, there are 164 stars above fourth magnitude in the Northern Hemisphere, of which 52 are on the Milky Way, or a percentage of 31·7. In the Southern Hemisphere there are 228 stars, of which 66 are on the Milky Way, or a percentage of 28·9. As the area of the heavens covered by the Milky Way does not probably exceed one-seventh of the whole sphere (Proctor assumed one-tenth), the percentage should be only 14·3, so that the number of bright stars is considerably more than that due to its area. As it may be objected, however, that the number of stars brighter than the fourth magnitude is too small to base any conclusion upon, I made an enumeration of all the stars in Heis's Atlas that lie on the Milky Way, and found the number to be 1,186. Now, the total number of objects shown by Heis (excluding variable stars, clusters, and nebulæ) is from his catalogue 5,356, so that for all the stars visible to the naked eye in this country (down to 6·3 magnitude) the percentage of stars on the Milky Way is 22·1, or about one and a half times that due to its area.

A similar count was made by Colonel Markwick, F.R.A.S., of the stars in Gould's charts of the Southern Hemisphere ('Uranometria Argentina'), and he finds that, out of 228 stars brighter than the fourth magnitude, there are 121 on the Milky Way, or a percentage of 53 ; and for the total number shown down to the seventh magnitude inclusive there are 3,072 on the Milky Way, out of 6,694, or a percentage of 45·8. From a careful calculation of the area of the Milky Way as shown in these charts, Colonel Markwick finds that it covers an area equal to one-third of the whole hemisphere, or 33·3 per cent. From these figures it will be seen that there is a marked tendency in the Southern bright stars also to aggregation on the Milky Way.

The apparent connection of some of the naked-eye stars with the brighter portions of the Milky Way is in some cases remarkable. The stars α, β, γ, η, and κ Cassiopeiæ mark a very luminous spot of milky light. The stars ι, κ, and λ Andromedæ mark another. δ, ϵ, and ζ Cephei lie near the edge of a 'coal-sack,' or dark space, in the midst of a luminous region. The stars ϵ, ξ, ζ, and o Persei mark an offshoot from the Galaxy in the direction of the Pleiades. The remarkably bright oblong spot in Cygnus includes the stars β, γ, η, ϕ, the variable χ Cygni, and other smaller stars. The stars forming Sagitta are situated in a bright portion of the Milky Way, and those forming the Dolphin's Rhomb in a fainter offshoot. The stars 67, 68, and 70 Ophiuchi lie at the extremity of a luminous spot on the broken branch in Ophiuchus. The stars λ, 6, 9, and 12 Aquilæ are ranged along the northern border of a bright spot in Sobieski's Shield; and other interesting cases might be pointed out.

Many attempts have been made to form a satisfactory theory of the construction of the Milky Way, but these efforts have been hitherto attended with but little success. This is not surprising, as the problem is one of great difficulty. The 'cloven disc' theory of Sir William Herschel, which figured for so many years in popular books on astronomy, although it was practically abandoned by that eminent astronomer in his later writings, has been well shown by Proctor to be utterly untenable, and it has now been rejected by nearly all astronomers. The real shape of the Galaxy is much more probably that of a ring (roughly speaking) than a disc. Proctor, however, inclined to the opinion that it is probably somewhat of a spiral form, and a figure of this supposed spiral is given by him in his 'Essays on Astronomy' (p. 331). In an interesting paper on the subject by Mr. J. R. Sutton in the *Illustrated Science Monthly*, some years since, he argues, and, I think, with considerable force, that Proctor's spiral does not account very satisfactorily for the observed features of the Milky Way, and he contends that its real form is what it seems to be, namely, that of a ring, roughly speaking, and actually cut across its width at the well-known gap in Argo. The aspect of the 'coal-sack' near the Southern Cross certainly suggests that it is a *real* opening through the Milky Way, and not merely due to a loop in the stream, as shown in Proctor's spiral. The 'coal-sacks' and dark spaces near the neck of the Swan are, as I have shown above, more apparent than real, and are, I think, probably due more to a sparseness of star distribution than to any real bifurcation of the Galactic stream in that vicinity. The separation of the two streams commences, according to Heis, near the star ζ Aquilæ, and, according to Sir J. Herschel's drawing, the streams unite again in Scorpio. Heis's delineation shows that the continuity of the western branch in Ophiuchus is interrupted for a width of only 6° north of μ Ophiuchi. The portions of this branch extending from Aquila to 70 Ophiuchi are tolerably bright, and do not agree well with the supposed great increase in distance at this point indicated by Proctor's spiral. Even in the middle of the gap in Ophiuchus, Heis shows a somewhat bright spot between μ and ν Ophiuchi.

Gould considered the phenomenon of the Milky Way as probably 'the resultant of two or more superposed Galaxies,' and certainly the complicated structure and gradations of brightness shown in Heis's drawing, especially in Cepheus and Cygnus, seem to favour this hypothesis. It is possible, however, that the brighter portions may be due to a *real* clustering of the smaller stars, which have perhaps been swayed into their present position by the attractive influence of the larger stars. This view of its structure would account for the occurrence of dark spaces close to luminous portions, which form so remarkable a feature in Cepheus, Cygnus, Perseus, Scorpio, and near the Southern Cross. Photography will probably throw some light on this point.

The observed excess of bright stars on the portion of the heavens covered by the Milky Way might be explained by supposing the Galactic ring to be placed at a much greater distance from the earth than the general star sphere. If we suppose the component stars of the larger or more extended group to be scattered over the heavens with some general approach to uniformity, and that the Milky Way contains its own proportion of bright stars, but wholly separated from the others by a starless interval, then, when the two systems are seen in the same direction, an increase in the number of the brighter stars would necessarily follow. On this hypothesis, it might be expected that some of the brighter stars would show a measurable parallax, while in others the parallax would be insensible. This we find to be actually the case. On this view of the matter, we should conclude that stars like α Centauri, 61 Cygni, Sirius, and Altair, which have a measurable parallax and a considerable 'proper motion,' are not connected with the same group as those stars which have no measurable parallax and very small proper motions, like α Cygni and α Orionis. There might, of course, be exceptions to this general rule, some stars having a perceptible proper motion, but with no *measurable* parallax.

Celoria advanced the theory that the Milky Way consists of two galactic rings inclined to each other at an angle of 19° or 20°, and that one of these consists chiefly of bright stars, and the other of the fainter stars. These faint or distant stars would be—according to Celoria—included in a great circle passing through Sagitta, Auriga, Monoceros, and Scutum. The other ring would include the branch of the Milky Way in Ophiuchus, and those in Orion, the Hyades, Pleiades, and the so-called belt of bright stars described by Sir John Herschel and Gould. Ristenpart also thinks that the Milky Way lies in two planes, which are slightly inclined to each other.

Easton, in 'A New Theory of the Milky Way,'[1] calls attention to the fact—which seems to be usually 'given less importance than it merits'—that the Milky Way near Aquila is much brighter than it is in Monoceros. This would imply that the stars which produce the light of the Galaxy are more numerous near the eighteenth hour of right ascension than they are near the sixth hour. Sir William Herschel's 'gauges' gave a mean of about 161 stars in the field of view of his large telescope in Aquila, and 82 stars in Monoceros. Celoria also found that stars to about the eleventh magnitude are much more numerous in Aquila than in the opposite region of the sky near Monoceros. Houzeau's observations of bright spots in the Milky Way are found by Easton to confirm this view. Gould found 'the brightest portion of the Milky Way to be unquestionably in *Sagittarius*,' and my own observations in India confirm this conclusion. Easton finds that, '*for the fainter stars taken as a whole, the Milky Way is widest in its brightest part.*' (The italics are Easton's.)

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[1] *Astrophysical Journal*, 1900, p. 136.

Easton thinks that the Milky Way between α and β Cygni is 'much nearer to us than the average.' 'The region between 68 (A) and β Cygni is richer in stars than any other zone in Argelander's "Durchmusterung."' Sir W. Herschel found one of his maxima of 'gauges' here—588 stars in the field of his telescope. Easton thinks that the 'central accumulation of the Milky Way' probably lies in this direction, and advances the theory that its general form may be that of a vast spiral nebula, the so-called 'solar cluster' being 'the expression of the central condensation of the Galactic system itself, composed for the most part of suns comparable with our own (and which must thus embrace most of the bright stars to the ninth or tenth magnitude).'

The Stellar Universe.—The late Mr. Proctor was of opinion that all the visible stars, and 'all the nebulæ hitherto discovered, whether gaseous or stellar, irregular, planetary, ring-formed, or elliptic, exist within the limits of the sidereal system.' This is probably true. If 'external universes' exist, they are not visible in our telescopes. There seems to be no escape from the conclusion that our sun and solar system form members of a limited universe. For were the stars scattered through infinite space with any approach to uniformity, it may be shown that the whole heavens would shine with the brightness of the sun. As the surface of a sphere varies as the square of the radius, and light inversely as the square of the distance (or radius of the star-sphere at any point), we have the diminished light of the stars exactly counterbalanced by their increased number at any distance. For a distance of, say, ten times the distance of the nearest star (or, rather, star-sphere) the light of each star would be diminished one hundred times (ten multiplied by ten); but the total number of stars at this distance would be one hundred times greater, so that the total starlight would be the same. This would be true for all distances. The total light will therefore (by addition) be proportional to the distance, and hence for an infinite distance we should have a continuous blaze of light over the whole surface of the visible heavens. Far from this being the case, the total amount of starlight on the clearest nights is very small (only a small fraction of moonlight), and portions of the sky, even in large telescopes, seem absolutely black. In a photograph of a rich region of the Milky Way in Cygnus (near η Cygni) by Dr. Roberts, there are about 30,000 stars on an area of about four square degrees. This gives for the whole heavens (41,253 square degrees) a total of about 300,000,000 stars—a comparatively small number. On a photograph of the Pleiades taken at the Paris Observatory with an exposure of three hours, there are 2,326 stars, where ordinary eyesight can see only six or seven. As this plate includes about three square degrees, this gives for the whole heavens a total of only 33,000,000. But other regions of the sky show a much smaller number, and we may safely assume that, when the whole sky has been photographed, the total of all the stars to the seventeenth magnitude (about the faintest visible in the great Yerkes telescope) will not much exceed 100,000,000. Possibly larger telescopes, more sensitive plates, and longer exposures may hereafter sensibly increase this total; but even if we multiply the number found above by ten, we must still consider the *visible* stars as finite in number. The way in which some of the faint stars in the chart of the Pleiades and elsewhere seem mixed up with the nebulous matter, and the nebulæ with the brightest stars, suggests the idea that these smaller stars are probably faint, owing to their small size rather than to immensity of distance, and probably belong to the same family of which the brighter stars are evidently components. Many of the fainter stars, however, probably lie far behind the Pleiades, and do not form members of the group visible to the naked eye.

It was long since suggested that the light of very distant stars may possibly be absorbed by the ether of space; but as this view of the matter now seems improbable, we must have recourse to some other hypothesis to explain the very limited number of the *visible* stars.

In my 'Planetary and Stellar Studies' (1888) I have suggested a possible thinning out of the ether beyond the bounds of our visible universe, which would evidently have the effect of cutting off for ever the light of external galaxies. In the absence, however, of evidence in favour of this hypothesis, it will perhaps be safer to assume that, if these external universes exist, they are probably invisible to us owing to immensity of distance, the spaces separating each galaxy from its neighbours being supposed to be very great compared with the dimensions of each universe. We know that the Solar System, of which our earth forms a member, is surrounded on all sides by a starless sphere, the diameter of which is very great compared with the diameter of the planetary system. Assuming the distance of the nearest fixed star—α Centauri—at twenty-five billions of miles (corresponding to a parallax of 0·75″), we have the diameter of this void sphere fifty billions of miles. If we call the Solar System a system of the first order, we may consider all the visible stars, clusters, and nebulæ, including the Milky Way, as forming a system of the second order; and as we may consider the members composing this system as finite in number (as shown above), we may also consider the number of systems of the second order as finite also. We may further consider all the systems of the second order as together forming a system of the third order, and so on to the fourth and higher orders. But we need not go further than the third order, for if, as I have shown elsewhere, light would probably take millions of years to reach us from an external universe of the second order, surely the altogether inconceivable distance of systems of the third order would sufficiently account for their light not having yet reached us, although travelling towards our earth for possibly billions of years!

The Nebular Hypothesis.—The famous Nebular Hypothesis of Laplace was advanced to explain the formation of the solar system by the rotation and condensation of a gaseous nebula. The discovery of the 'spiral nebulæ' in recent years seems to justify us in extending the hypothesis to the formation of star clusters and stellar systems. In these wonderful objects we seem to see before our eyes the slow formation of suns and systems. Instead, however, of supposing, as Laplace did, the formation of bodies from 'rings' detached from a rotating nebulous mass of spherical or ellipsoidal shape, we now see that the nebulous mass first assumes a flattened, disc-like form, and then *masses*, not rings, are detached from the parent mass, to be afterwards consolidated into stars or suns. If this be the mode of formation of stellar systems, it seems highly probable that the Solar System was formed in a similar manner.

With reference to 'stellar evolution,' Professor Pickering thinks that stars showing the 'Orion type' of spectrum are probably 'in an early stage of development,' and that stars with spectra of the fifth type may possibly 'form a connecting link between the Orion stars and those of the nebulæ.' After the Orion stars come the stars of Type I. (the Sirian), then those of Type II. (which includes our own sun), and lastly Type III., which is the oldest, and probably belongs to stars which are approaching the total extinction of their light. In this view of the 'evolutional order' Sir William Huggins concurs. He is disposed to think that the hottest stars must be looked for among those of the Solar type. The 'evolutional order' now adopted by Huggins seems to be (omitting the so-called Wolf-Rayet stars), Bellatrix, Rigel, α Cygni, Regulus, Vega, Sirius, Castor (fainter component), Altair, Procyon, γ Cygni, Capella (hottest star), Arcturus, and Betelgeuse, the youngest being Bellatrix, and the oldest Betelgeuse.

That stars of the Sirian type are less dense than those in the Solar stage has been recently proved by calculations by Dr. Roberts (of South Africa) and Professor Russell of the densities of the Algol type variables, which show spectra of the Sirian type. The investigation shows that the average density of these stars is less than that of water, and that they are therefore in an earlier stage of condensation.

Dr. See accounts for the origin of binary stars by supposing a rotating nebulous mass to assume the dumb-bell form by the force of the rotation. Eventually it would separate into two bodies which would then form a 'spectroscopic binary'; and afterwards the two bodies would, by the effect of tidal action, move further apart, still revolving round their common centre of gravity in elliptic orbits of large eccentricity, thus forming the binary stars visible in the telescope. Numerous double nebulæ, or nebulæ with two nuclei, are visible in the heavens. These probably form the first stage in the evolution of binary stars.

APPENDIX

Note A.

The following is a list of the constellations now in use, with the English equivalents and the Arabic and other names of the principal stars:

Andromeda, *the Chained Lady:*
- α, Alpheratz.
- β, Mirach, Mizar.
- γ, Almach.

Antlia, *the Air-Pump.*

Apus, *the Bird of Paradise.*

Aquarius, *the Water-Bearer:*
- α, Sadalmelik.
- β, Sadalsund.
- γ, Gjenula.
- δ, Skat.

Aquila, *the Eagle:*
- α, Altair.
- β, Alshain.
- γ, Tarazed.

Ara, *the Altar.*

Argo, *the Ship Argo,* divided into:
- Carina, *the Keel.*
- Malus, *the Mast.*
- Puppis, *the Poop.*
- Vela, *the Sails.*
- α, Canopus.
- ι, Tureïs.

Aries, *the Ram:*
- α, Hamal.
- β, Sheratan.
- γ, Mesartim.

Auriga, *the Charioteer:*
- α, Capella.
- β, Menkalinan.
- γ, Nath (now β Tauri).

Boötes, *the Herdsman:*
- α, Arcturus.
- β, Nekkar.
- ε, Izar, Mizar, Mirac.
- η, Muphrid.
- μ, Alkalarops.

Cælum, *the Sculptor's Tools.*

Camelopardalis, *the Giraffe.*

Cancer, *the Crab:*
- ζ Tegmine.

Canes Venatici, *the Hunting Dogs:*
- α, Cor Caroli.

Canis Major, *the Great Dog:*
- α, Sirius, Mazzaroth.
- β, Mirzam.
- δ, Wezen.
- ε, Adara.
- η, Aludra.
- ζ, Phurud.

Canis Minor, *the Little Dog:*
- α, Procyon.
- β, Gomeisa.

Capricornus, *the Goat:*
- α, Prima Giedi.
- α_2, Secunda Giedi.
- δ, Deneb Algiedi.

Cassiopeia, *the Lady in the Chair:*
- α, Schedar.
- β, Chaph.

Centaurus *the Centaur.*

Cepheus, *the King Cepheus:*
α, Alderamin.
β, Alphirk.
γ, Errai.
Cetus, *the Whale:*
α, Menkar.
β, Diphda.
γ, Kaffaljidhma.
ζ, Baten Kaitos.
o, Mira.
Chamæleon, *the Chameleon.*
Circinus, *the Compass.*
Columba, *the Dove:*
α, Phaet.
Coma Berenices, *Berenice's Hair.*
Corona Borealis, *the Northern Crown:*
α, Alphecca, Alfeta, Gemma Foca.
Corona Australis, *the Southern Crown.*
Corvus, *the Crow:*
α, Alchiba, Algorab.
δ, Algores.
Crater, *the Cup:*
α, Alkes.
Crux, *the Southern Cross.*
Cygnus, *the Swan:*
α, Deneb, Arided.
β, Albireo.
π^1, Azelfafage.
Delphinus, *the Dolphin.*
Dorado, *the Sword-Fish.*
Draco, *the Dragon.*
α, Thuban.
β, Alwaid.
γ, Etanin.
λ, Giauzar.
ξ, Grummium.
Equuleus: *the Little Horse.*
Eridanus, *the River Eridanus:*
α, Achernar.
β, Cursa.
γ, Zaurac.
η, Azha.
o, Beïd.
o_2, Keid, Al-Kaid.
Fornax, *the Furnace.*
Gemini, *the Twins:*
α, Castor.
β, Pollux.
γ, Alhena.
δ, Wasat.
ϵ, Websuta.
ζ, Mekbuda.
μ, Tejat Post.
Grus, *the Crane.*
Hercules, *Hercules:*
α, Ras Algethi.
β, Corneforos.
κ, Marsic.
Masym.
Hydra, *the Sea-Serpent:*
α, Alphard, Cor Hydræ.
Hydras, *the Water-Snake.*
Indus, *the Indian.*
Lacerta, *the Lizard.*
Leo, *the Lion:*
α, Regulus, Cor Leonis.
β, Denebola.
γ, Algeiba.
δ, Zosma.
μ Rassalas.
Leo Minor, *the Little Lion.*
Lepus, *the Hare:*
α, Arneb.
β, Nihal.
Libra, *the Balance:*
α, Kiffa Australis, Zuben el Genabi.
β, Kiffa Borealis, Zuben el Chameli.
γ, Zuben Hakrabi.
Lyra, *the Lyre:*
α, Vega.
β, Sheliak.
γ, Sulaphat.
Mensa, *the Table.*
Microscopium, *the Microscope.*
Monoceros, *the Unicorn.*
Musca, *the Fly.*
Norma, *the Rule.*
Octans, *the Octant.*
Ophiuchus, *the Serpent-Bearer:*
α, Ras Alhague, Ras Algethi.
β, Cebalrai.
λ, Marfik.
Orion, *the Giant Hunter:*
α, Betelgeuse.
β, Rigel.
γ, Bellatrix.
δ, Mintaka.

ε, Alnitam.
ζ Alnitak.
Pavo, *the Peacock.*
Pegasus, *the Flying Horse:*
α, Markab.
β, Scheat.
γ, Algenib.
ζ, Homan.
ε, Enif.
Perseus, *the Rescuer:*
α, Mirfak.
β, Algol.
Phœnix, *the Phœnix.*
Pictor, *the Painter's Easel.*
Pisces, *the Fishes:*
α, Kaitan, Okda.
Piscis Australis, *the Southern Fish:*
α, Fomalhaut.
Reticulum, *the Net.*
Sagitta, *the Arrow.*
Sagittarius, *the Archer:*
ε, Kaus Australis.
Scorpion, *the Scorpion:*
α, Antares, Cor Scorpii.
β, Iklil, Iklil-al-Jebhah.
λ, Shaulah.
Sculptor, *the Sculptor's Workshop.*
Serpens, *the Serpent:*
α, Unukalhai.
Sextans, *the Sextant.*
Taurus, *the Bull:*
α, Aldebaran.
β, Nath.
Telescopium, *the Telescope.*
Toucan, *the Toucan.*
Triangulum, *the Triangle:*
α, Mothallath.
Triangulum Australis, *the Southern Triangle.*
Ursa Major, *the Great Bear:*
α, Dubhe.
β, Merak.
γ, Phecda.
δ, Megrez.
ε, Alioth.
ζ, Mizar.
η, Alkaid, Benetnasch.
Fl. 80, Alcor, Suhà.
Ursa Minor, *the Little Bear:*
α, Polaris.
β, Kochab.
Virgo, *the Virgin:*
α, Spica.
β, Zavijava.
γ, Porrima, Postvarta.
ε, Vindemiatrix, Mukdim.
Volans, *the Flying Fish.*
Vulpecula, *the Fox.*

After the Greek letters are exhausted in each constellation, the fainter stars visible to the naked eye are usually designated by their number in Flamsteed's Catalogue, published in the year 1712, from observations made at the Greenwich Observatory. Flamsteed was the first Astronomer Royal of England. When these are used up, the star is identified by its number in some catalogue, such as Lalande's, Lacaille's, etc.

Note B.

If r be the radius of the sphere,

$$\text{Area of surface} = 4\pi r^2.$$

To find the area in square degrees we must express r in degrees, or putting $r = \frac{180°}{\pi}$,

$$\text{Area} = 4\pi\left(\frac{180}{\pi}\right)^2$$
$$= 4\pi \times \frac{180}{\pi} \times \frac{180}{\pi}$$
$$= 720 \times \frac{180}{\pi}$$
$$= 720 \times 57^\circ \cdot 29578$$
$$= 41253 \text{ nearly.}$$

I have found the following relation between the 'angular unit,' or 'radian' (that is, the angle at the centre of a circle subtended by an arc equal in length to the radius) expressed in seconds of arc, and the area of a sphere in square degrees :

$$\text{Radian} = \frac{180}{\pi} = A^\circ$$

$$\therefore \text{ Area of a sphere} = 720 \times A^\circ \text{ (as above)}$$
$$= \frac{720 \times a''}{3600}$$
$$= \frac{a''}{5}$$

$$[a'' = 206{,}265 \text{ and } \frac{206265}{5} = 41253, \text{ as above}].$$

Note C.

The following are the twenty brightest stars in the heavens, according to the Harvard photometric measures :

Star.	Photom. Magni.	Star.	Photom. Magn.
*1. Sirius	−1·62	*11. β Centauri	0·83
2. Canopus	−0·96	*12. α Orionis (var.)	0·94
3. Arcturus	0·07	*13. α Crucis	1·02
*4. Vega	0·10	14. Aldebaran	1·07
*5. α Centauri	0·20	15. Spica...	1·09
*6. Capella	0·24	16. Pollux	1·25
7. Rigel	0·28	*17. α Cygni	1·25
*8. Procyon	0·47	18. Fomalhaut	1·31
9. α Eridani	0·51	19. Regulus	1·34
*10. Altair	0·74	*20. Antares	1·44

Those marked with an asterisk lie on or near the Milky Way.

NOTE D.—LIST OF REMARKABLE RED STARS.

(Only the very reddest stars and those brighter than the ninth magnitude are given.)

Star.	R.A. 1900. h. m. s.	Decl. 1900. ° ′	Mag.	Remarks.
Birmingham 4 ...	0 14 36	+44 9	8·2	'Almost vermilion' (Franks). 'Intense red colour, most wonderful' (Espin).
DM+34,56 ...	0 22 15	+35 3	8·1	'Presque rouge absolu' (Dunér).
R Sculptoris ...	1 22 22	−33 3·5	Var.	5·7 to 8·0. 'Intense scarlet' (Gould).
V Camelopardalis	3 33 12	+62 19·4	Var.	7·3 to 8·8. 'Fiery red' (Dreyer).
Birm. 85 ...	4 45 14	+28 21·4	8	'Extraordinary ruby colour' (Sir J. Herschel). 'Very red' (Espin).
R Leporis ...	4 55 3	−14 57·4	Var.	6·7 to 8·5. 'Most intense crimson' (Hind).
Birm. 96 ...	5 0 14	+ 1 2·4	6·6	'Fiery red' (Doberck). 'Fine ruby' (Webb).
Birm. 120 ...	5 39 6	+24 22·6	8·5	'Presque rouge absolu' (Dunér).
Birm. 121 ...	5 39 42	+20 39·2	7·7	'Splendid crimson' (Birmingham). 'Full red' (Copeland).
Birm. 148 ...	6 29 40	+38 31·6	6·3	'Splendid red' (Dreyer). 'Colour wonderful' (Espin).
Birm. 232 ...	9 57 53	−59 42·9	7¾	'Scarlet' (Sir J. Herschel). 'Very red' (Thome).
V Hydræ ...	10 46 46	−20 43·2	Var.	6·7 to 9·5. 'Copper red, most magnificent' (Dreyer). 'Magnificent, blood red' (Espin).
R Crateris ...	10 55 38	−17 47·3	Var.	'Scarlet' (Winnecke). 'Very intense ruby' (Webb).
W Hydræ ...	13 43 23	−27 52	Var.	6·7 to 8·0. 'Deep red or crimson' (Burnham). 'Very red' (Espin).
Birm. 347 ...	15 16 8	−75 30·1	8¾	'Very high red' (Sir J. Herschel).
Birm. 396 ...	16 54 22	−54 53·4	8½	'Intense ruby red' (Sir J. Herschel).
Birm. 410 ...	17 23 49	−19 22·5	7·8	'Fine ruby' (Birmingham). 'Intense red' (Copeland). 'Very red' (Espin).

NOTE D.—LIST OF REMARKABLE RED STARS—*continued.*

Star.	R.A. 1900.	Decl. 1900.	Mag.	Remarks.
	H. M. S.	° ′		
Birm. 418 ...	17 39 4	−18 36·2	8·5	'Remarkable red' (Sir J. Herschel). 'Very intense red' (Burton).
T Lyræ... ...	18 28 54	+36 55·0	Var.	7·2 to 7·8. 'Intense' (Secchi). 'Fiery red, superb' (Franks). 'Crimson, magnificent' (Espin).
Birm. 464 ...	18 44 30	− 8 2·4	7·1	'Most remarkable red' (Sir J. Herschel). 'Very fine red' (Birmingham). 'Very red' (Espin).
V Aquilæ ...	18 59 4	− 5 50·0	Var.	6·5 to 8·0. 'Truly striking and wonderful' (Webb). 'Very red' (Espin). 'Presque rouge absolu' (Dunér).
Z Cygni ...	19 58 38	+49 45·9	Var.	7·1 to 12·0. Colour 9·0 on a scale of 1 to 10.
RS Cygni ...	20 9 45	+38 27·8	Var.	6·0 to 10·0. Colour 9·4 on a scale of 1 to 10.
Birm. 545 ...	20 11 15	−21 40·1	7·7	'Pure red; perhaps the finest of any ruby stars' (Sir J. Herschel).
U Cygni ...	20 16 30	+47 34·7	Var.	7·0 to 11·6. Colour 9·3. 'One of the loveliest hues in the sky' (Webb). 'Very red' (Espin).
V Cygni ...	20 38 5	+47 47·1	Var.	6·8 to 13·5. Colour 8·3. 'Very red' (Birmingham). 'Presque rouge absolu' (Dunér).
S Cephei ...	21 36 28	+78 10·3	Var.	7·4 to 12·3. Colour 9·1. 'Very deep red' (Copeland). 'Presque rouge absolu' (Dunér).
RV Cygni ...	21 39 8	+37 33·6	Var.	7·1 to 9·3. 'Splendid red' (Birmingham). 'Very fine colour' (Webb). 'Orange vermilion' (Franks). 'Presque rouge absolu' (Dunér).
Birm. 658 ...	23 56 9	+59 48	7·8	'A very fine ruby, intense and beautiful, pure red' (Webb). 'Presque rouge absolu' (Dunér).

NOTE E.—PARALLAX OF STARS.

According to the first principles of trigonometry, any object which subtends (or measures) 1″ of arc at the eye of an observer is distant from the eye 206,265 times its diameter. Hence, if the earth's mean distance from the sun (about 92,800,000 miles) subtends at a star an angle of 1″ of arc, the star's distance from the earth will be

$$92,800,000 \times 206,265 = 19,141,392,000,000 \text{ miles,}$$

or about 19 billions of miles.

To obtain the distance of α Centauri, of which the parallax is $\frac{3}{4}''$, we must divide the above result by $\frac{3}{4}$, or, which is the same thing, multiply by $\frac{4}{3}$. This gives

Distance of α Centauri = 25,521,856,000,000 miles,

or about 25 billions of miles.

For a parallax of $\frac{1}{2}''$ the distance would be about $38\frac{1}{4}$ billions of miles. For $\frac{1}{10}''$, about $191\frac{1}{2}$ billions, and for $\frac{1}{100}''$, about 1,914 billions of miles. The earth's mean distance from the sun is called 'the astronomical unit.' Its value, according to Harkness, is

$$92,796,950 \pm 59,715 \text{ miles.}$$

The distance of a star is sometimes expressed in 'light years'—that is, the number of years which light would take to reach us from a star. As light travels at the rate of about 186,300 miles a second, this leads to a simple formula for finding the distance in 'light years,' if the parallax (p) is known. If we divide the distance found above for a parallax of 1″ by the number of seconds in a year multiplied by the velocity of light, and divide again by the parallax, we find

$$\text{Light years} = \frac{3{\cdot}258}{p}.$$

The 'light year' is sometimes taken as the 'unit' of stellar distances. Mr. Monck has suggested as a 'unit' the distance of a star whose parallax is 1″ of arc. On this scale the distance of a star would be represented by $\frac{1}{p}$.

NOTE F.

If p be the parallax of a star, its distance from the earth will be $\frac{206265}{p}$, in terms of the earth's mean distance from the sun. As light varies inversely as the square of the distance, if we square this result it will show how much the sun's light would be reduced if it were removed to the distance of the star. Dividing the logarithm of this by 0·4 (the logarithm of 2·512, the 'light ratio'), we obtain the reduction of light in stellar magnitudes. From this we must deduct the sun's stellar magnitude, and the difference will be the sun's magnitude if placed at the distance of the star. For α Centauri the calculation is as follows:

$$\frac{206265}{p} = \frac{206265}{0{\cdot}75} = 275020,$$

$$\text{and } \frac{2 \log 275020}{0{\cdot}4} = \frac{10{\cdot}8787286}{0{\cdot}4} = 27{\cdot}19.$$

$$\begin{array}{lr} \text{Deduct sun's stellar magnitude} & \underline{26{\cdot}5} \\ \text{and we have} & 0{\cdot}69 \end{array}$$

That is, the sun would be reduced to a star of about 0·69 if removed to the distance of α Centauri. As the magnitude of α Centauri is 0·20, it appears that the star is a little brighter than our sun, as it should be, owing to its larger mass.

From the above considerations I have deduced the following simple formula: If m = magnitude of sun seen at the distance of a star whose parallax is p, then

$$m = 5 \log \left(\frac{1}{p}\right) + 0{\cdot}07$$

(for sun's stellar magnitude $= -26{\cdot}5$).

If this assumed value for the sun's stellar magnitude is not quite correct, the formula will be slightly altered. If we assume the value $-26{\cdot}0$, then

$$m = 5 \log \left(\frac{1}{p}\right) + 0{\cdot}57.$$

If, on the other hand, we assume the value $-27{\cdot}0$, then

$$m = 5 \log \left(\frac{1}{p}\right) - 0{\cdot}43.$$

But probably the simple formula

$$m = 5 \log \left(\frac{1}{p}\right)$$

is near enough. For $p = 1''$,

$$m = 5 \log 1 = 0, \text{ or zero magnitude.}$$

For $p = \frac{1}{10}''$ we have

$$m = 5,$$

and for $p = \frac{1}{100}''$

$$m = 10.$$

Note G.

When the parallax and proper motion of a star are known, its actual velocity at right angles to the line of sight may be computed by the following formula:

Let p = parallax in seconds of arc,
m = proper motion seconds of arc.

Then velocity in miles per second $= \dfrac{2{\cdot}942\, m}{p}$.

Note H.

When the period and the semi-axis major of the orbit of a binary star are known, and also its parallax, the mass of the system can easily be computed in terms of the sun's mass. For if P be the period of revolution in years, d the semi-axis of the orbit (or mean distance), m and n the masses of the components, and M the sun's mass (or, more correctly, the combined mass of the sun and earth), we have by the laws of orbital motion:

$$P^2 : 1 :: \frac{d^3}{m+n} : \frac{1}{M};$$

$$\text{whence } m+n = \frac{d^3 M}{P^2}.$$

Now, if a be the semi-axis major of the orbit, and p the parallax of the star, we have $d=\frac{a}{p}$, and hence

$$m+n = \frac{\left(\frac{a}{p}\right)^3 M}{P^2} = \frac{a^3 M}{p^3 P^2},$$

or, if we put $M=1$,

$$m+n = \frac{a^3}{p^3 P^2}.$$

In the case of α Centauri, we have from Dr. See's orbit $P=81\cdot1$ years, $a=17\cdot70''$, and $p=0\cdot75''$, and hence

$$m+n = \frac{(17\cdot7)^3}{(0\cdot75)^3 \times (81\cdot1)^2} = 2\cdot00,$$

or the combined mass of the system is twice the sun's mass. Mean distance between components, $d=\frac{a}{p}=\frac{17\cdot70}{0\cdot75}=23\cdot6$ times the earth's mean distance from the sun.

Note I.

The following method of calculation is given by Dr. Dunér:

Let A = surface of the brighter star,
xA = surface of the fainter star,
1 = brightness of unit surface of the first star,
y = brightness of unit surface of the second star.

Then for Z Herculis, we have the equations

$$A + Axy = 3 \quad . \; . \; . \quad (1),$$
$$A = 2 \quad . \; . \; . \quad (2),$$
$$A - Ax + Axy = 1 \quad . \; . \; . \quad (3).$$

Subtracting (3) from (1), we have

$$Ax = 2;$$

and combining this with (2) we have

$$x=1,$$

and from (1) and (2)

$$Axy=1, \text{ and } \therefore y=\tfrac{1}{2}.$$

Hence the stars are of equal size, but one is twice as bright as the other.

To obtain a general expression for any Algol variable with unequal minima:

Let light at maximum $=M$,
Ditto at second minimum $=S$,
Ditto at principal minimum $=m$.

$$\text{Then } A+Axy=M \quad . \; . \; . \; (1),$$
$$A=S \quad . \; . \; . \; (2),$$
$$A-Ax+Axy=m \quad . \; . \; . \; (3).$$

Proceeding as before, we have

$$Ax=M-m,$$

$$\text{or } Sx=M-m, \text{ and } \therefore x=\frac{M-m}{S}.$$

$$\therefore \text{ from } (1)\ S+(M-m)y=M,$$

$$\text{and } \therefore y=\frac{M-S}{M-m}.$$

If there is no secondary minimum, as in Algol and other similar variables of this class, then equations (1) and (2) are equal, and $\therefore Axy=0$, and the companion is a dark body.

In the case of Algol, where the light at maximum is about three times the light at minimum, we have

$$x=\frac{3-1}{3}=\frac{2}{3}=0{\cdot}6666,$$

and the diameters of the two components are in the ratio of

$$1 : \sqrt{0{\cdot}6666}, \text{ or } 1 : 0{\cdot}816.$$

If the variation of an Algol variable is one and a half magnitudes, then light at maximum is equal to four times light at minimum, and we have

$$x=\frac{4-1}{4}=\frac{3}{4}=0{\cdot}75,$$

and the diameters are in the ratio of

$$1 : \sqrt{0{\cdot}75}, \text{ or } 1 : 0{\cdot}866.$$

NOTE K.

The brighter stars are usually designated by the letters of the Greek alphabet. They are as follows:

Letters.	Names.	Letters.	Names.	Letters.	Names.
Α, α ...	Alpha.	Ι, ι ...	Iota.	Ρ, ρ ...	Rho.
Β, β ...	Beta.	Κ, κ ...	Kappa.	Σ, σ ς ...	Sigma.
Γ, γ ...	Gamma.	Λ, λ ...	Lambda.	Τ, τ ...	Tau.
Δ, δ ...	Delta.	Μ, μ ...	Mu.	Υ, υ ...	Upsilon.
Ε, ε ...	Epsilon.	Ν, ν ...	Nu.	Φ, φ ...	Phi.
Ζ, ζ ...	Zeta.	Ξ, ξ ...	Xi.	Χ, χ ...	Chi.
Η, η ...	Eta.	Ο, ο ...	Omicron.	Ψ, ψ ...	Psi.
Θ, θ ...	Theta.	Π, π ...	Pi.	Ω, ω ...	Omega.

NOTE L.

The magnitude of the faintest star visible in any telescope may be found by the simple formula $m = 9 + 5$ log aperture (in *inches*). This gives the following:

Aperture. Inches.	Magnitude.	Aperture. Inches	Magnitude.	Aperture. Inches.	Magnitude.
1	9	6	12·89	16	15
1½	9·88	7	13·22	18	15·27
2	10·50	8	13·51	20	15·5
2½	11	9	13·77	25	16
3	11·38	10	14	30	16·38
4	12	12	14·4	36	16·78
5	12·49	14	14·73	40	17

To show stars of the twentieth magnitude—if any such exist—would require an aperture of 158·5 inches, or over 13 feet. Dr. Roberts finds that the faintest stars visible on his photographs are about the eighteenth magnitude. Photographs show fainter stars than any visible in the largest telescopes.

NOTE M.

While this volume was in the press, Messrs. Müller and Kempf of Potsdam announced their discovery of a remarkable variable star in the constellation Ursa Major, having the marvellously short period of 4 hours! It varies from about 7·8 to 8·6 magnitude. The duration of minimum is about 10 minutes. It is DM + 56°, 1400, and its position for 1900 is 9 h. 36 m. 44 s., N 56° 24·6′. This very interesting object lies about 20′ east of the star DM 56°, 1397 (6·67 mag. Harvard), and about 2° north-west of the 4½ magnitude star φ Ursæ Majoris. The fluctuations of light may be followed with a good binocular field-glass.

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